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Advanced Mobile Phone Service:

Cell-Site Hardware

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The hardware facilities of the AMPS cell site connect the mobile radio customer to the land telephone network and perform actions necessary for RF radiation, reception, and distribution; voice and data communications and processing; equipment testing, control, and reconfiguration; and call setup, supervision, and termination. Cell-site operational control is achieved partially through wired logic and partially through programmable controllers. This paper describes the cell-site functional groups, their physical characteristics and design, and the ways they interface with the rest of the AMPS system.

I. INTRODUCTION

In the AMPS system, the interface between the land telephone network and the radio paths to the mobiles occurs at the cell sites. In addition to performing functions needed for trunk termination and for radio transmission and reception, the cell site handles many semiautonomous functions under the general direction of the Mobile Telephone Switching Office (MTSO). Figure 1 is a block diagram of the major AMPS subsystems.

Cell sites have facilities to:

(*i*) Provide RF radiation, reception, and distribution.
(*ii*) Provide data communications with the MTSO and mobiles.
(*iii*) Locate mobiles.
(*iv*) Perform remotely ordered equipment testing.
(*v*) Perform equipment control and reconfiguration functions.
(*vi*) Perform voice-processing functions.
(*vii*) Perform call setup, call supervision, and call termination functions.

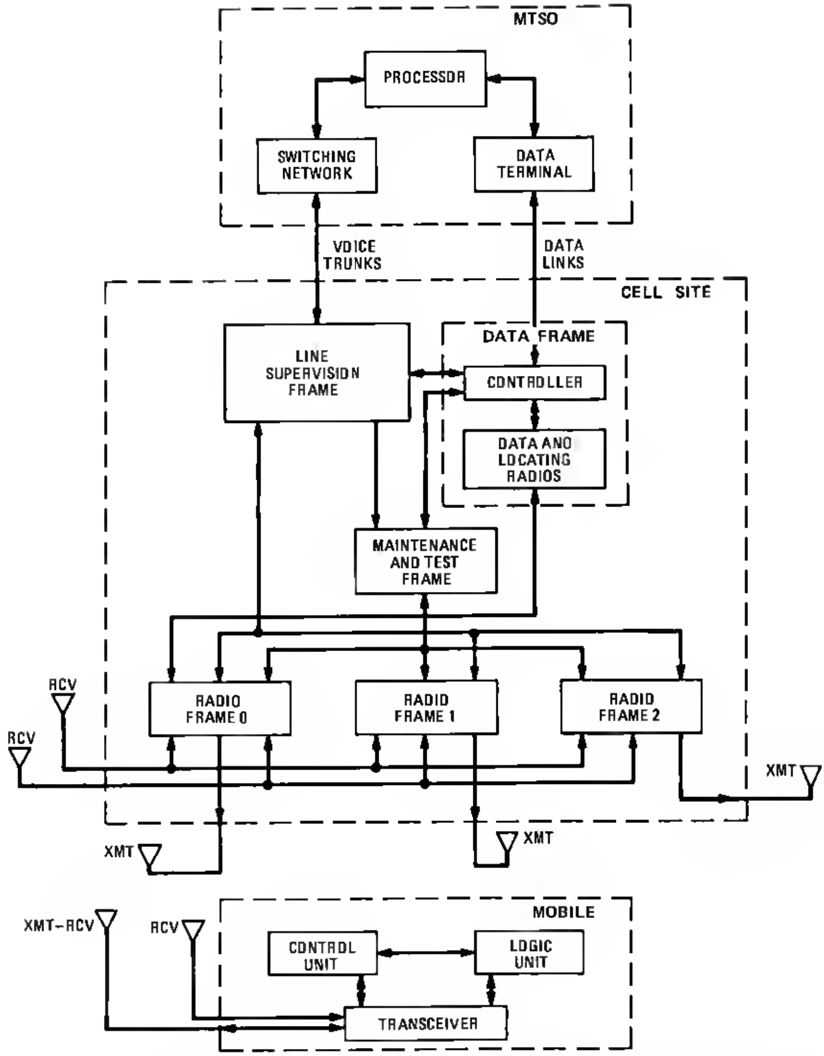


Fig. 1—AMPS major subsystems.

(*viii*) Handoff or receive from another cell site any mobile which has moved out of the normal service area of the cell site carrying the call.

Cell-site operations are controlled partially by wired logic and partially by programmable controllers. Control functions are redundant and can be reconfigured as needed to overcome a localized failure. A battery plant assures maintenance of service in case of commercial power outage. Facilities dependent upon traffic requirements in each cell coverage area are modular so that additional units may be installed as needed to match busy-hour traffic levels. This will ensure that plant investment can grow sensibly as a function of anticipated revenues.

Figure 2 is an isometric view of a typical cell site with a capacity of 48 voice channels. The precise number of frames at each site is a function of the voice channel requirements for that site. There are four frame codes, and the smallest size cell site requires one of each code. Each radio frame has a maximum capacity of 16 radios. When the number of voice radios grows beyond 16, another radio frame must be added. Each line supervision frame (LSF) can handle 48 voice channels and, when this number is exceeded, another LSF is added. A single data frame (DF) and a single maintenance test frame (MTF) are necessary regardless of the number of voice radios in the cell site. The maximum size of a cell site is 144 voice radios, which would require a total of 14 frames: nine radio frames, three line supervision frames, one data frame, and one maintenance test frame.* The discussion in this paper of the functional design of the cell site parallels the organization of these frames.

Section II describes the data frame, which serves as the master control center for the cell site. Section III describes the line supervision frame, which interfaces the four-wire voice trunks (originating at the MTSO) with the cell-site voice-radio transceivers. Section IV describes the radio frame, which is composed of two bays. Section V describes the maintenance and test frame, which gives the cell site the ability—through the use of another programmable controller—to test for troubles in the radio and audio equipment. Section VI describes the power system. Section VII describes the physical design of a cell site.

II. DATA FRAME

The data frame (see Figs. 3 and 4) contains the equipment for major cell-site control functions, which include communication with the MTSO, control of voice and data communication with mobiles, and communication with the controller in the maintenance test frame. Communication between controllers is necessary for requesting performance of specific tests and for receiving results. The DF contains both hardwired logic and programmable controllers. Only one set of hardwired logic and one controller is needed per cell site regardless of the number of voice radios. Because of the critical functions performed in the DF, redundancy of all subassemblies is provided to assure continuation of service in the presence of a failure. The DF can reconfigure itself under the direction of the MTSO, which maintains service by permitting any malfunctioning subassembly to be replaced with an off-line redundant unit.

The data frame (see Fig. 4) contains five major subsystems:

* In addition to these transmission and control frames, four additional WE 111A power system frames and an associated battery system are required for the maximum size cell site.

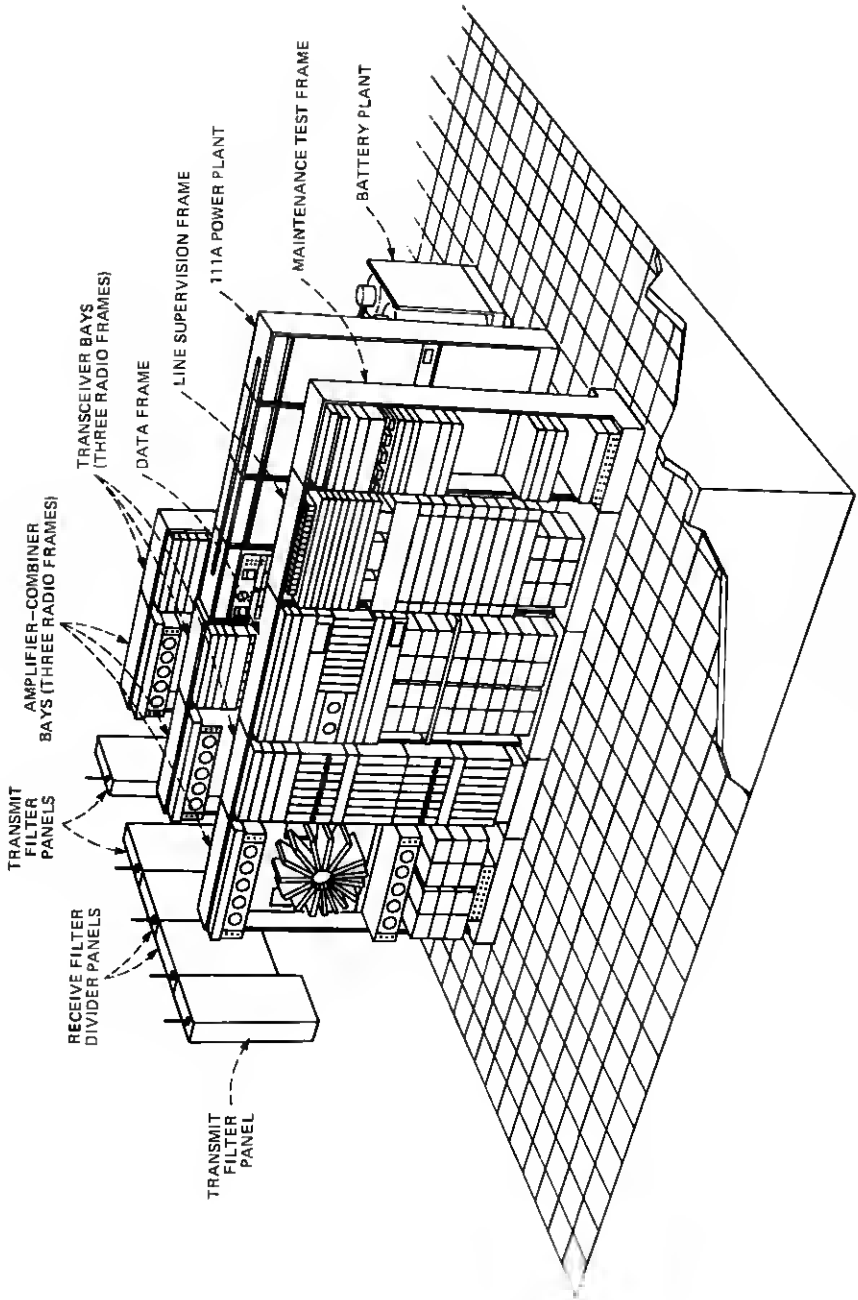


Fig. 2—Typical 48 channel cell-site.

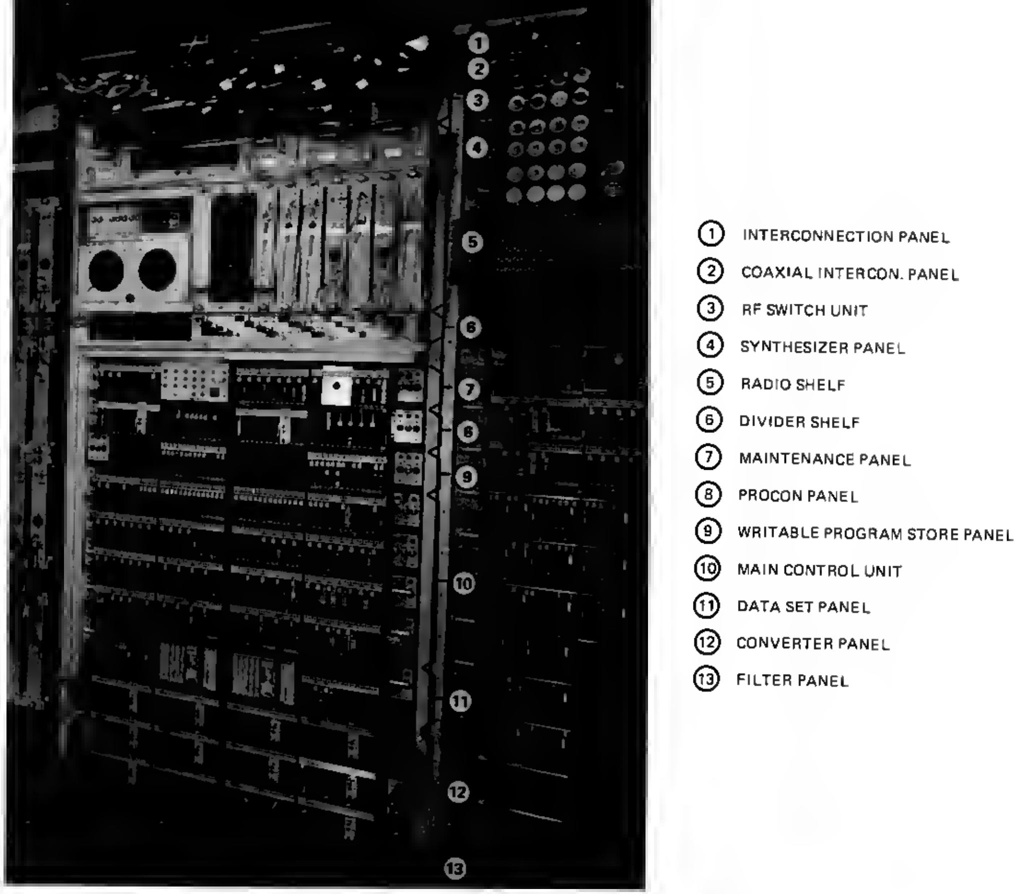


Fig. 3—Data frame.

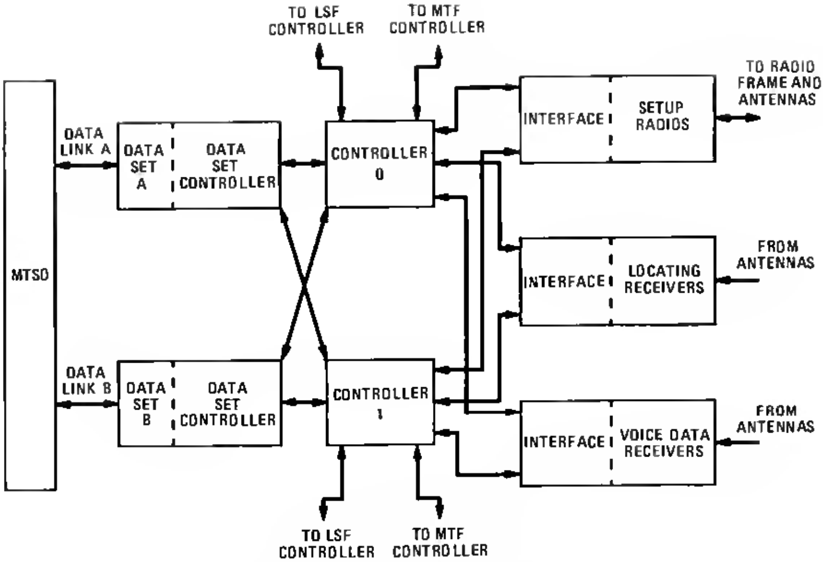


Fig. 4—Data frame block diagram.

(*i*) Land data links, described in Section 2.1.
(*ii*) Controllers described in Section 2.2.
(*iii*) Setup radio communication, described in Section 2.3.
(*iv*) Locating radios, described in Section 2.4.
(*v*) Voice-channel data communications, described in Section 2.5.

2.1 Land data links

Data communication between the MTSO and each cell site takes place over two redundant data links connecting Western Electric 201D data sets at each termination. The 201D data set operates at a 2.4-kb/s rate and supplies TTL level outputs so that no buffering is required between it and the DF logic. The data set controller converts the 32-bit serial messages into 16-bit parallel words for transfer to the controllers. The 201D also can configure itself for loop-around testing under remote control of the MTSO. This feature is essential for maintenance because the cell sites will normally be unmanned. The data sets and the data set interfaces also operate in the reverse direction to take and transmit data from tbe controllers to the MTSO.

2.2 Controllars

The controller of the data frame (see Fig. 5) consists of a PROCON, a writable store unit (WSU), a parity generator and checker, and a data bus to connect the PROCON to the numerous peripherals with which it must communicate. All units are provided redundantly to assure continuation of service in the presence of failure.

The PROCON is a small general-purpose programmable controller,

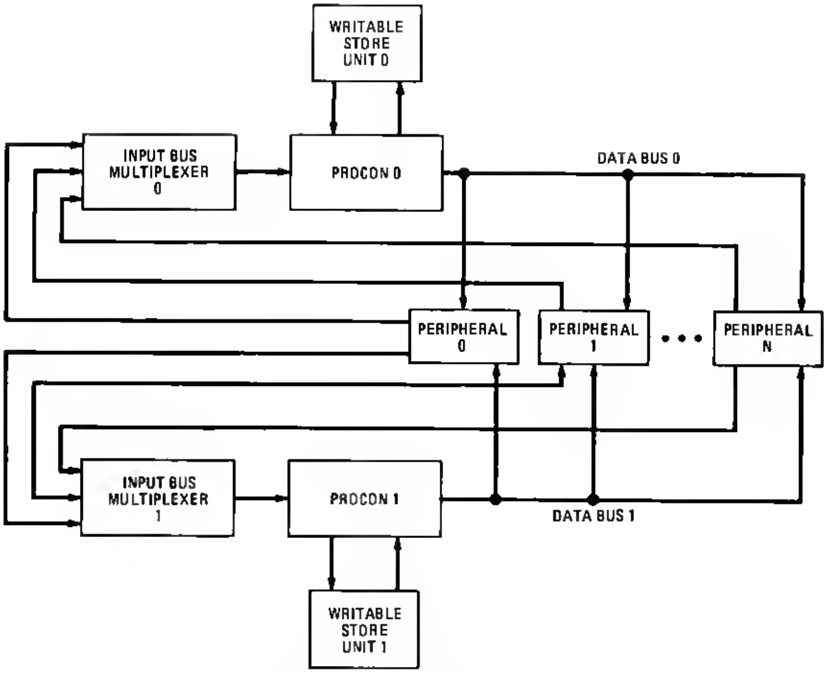


Fig. 5—Data frame controller.

developed at Bell Laboratories, designed to have sequencing and control functions with very high reliability. It is self-checking; an ASW (all seems well) signal indicates the presence or absence of a failure. The redundant PROCON recognizes this indication and reports failure to the MTSO. The MTSO will then use the properly functioning PROCON for further cell-site control and will print out in a maintenance center a request to dispatch a craftsperson to the cell site to correct the problem.

PROCON processes 16-bit parallel data words but uses 24-bit words for program instructions. It contains data manipulation units (DMU), a control unit (CU-16), and program storage units (PSU). The DMU contains instruction decoders, internal registers, logical/arithmetic capability, and peripheral communication logic. The control unit contains program-addressing logic, clock distribution, and fault-detection circuits. Each PSU board contains 2048 (2K) 24-bit words of read-only memory (ROM). The PROCON contains 4000 words of ROM and accesses an additional 4000 24-bit words of random-access memory (RAM) in its associated WSU. This increases its effective program store capacity to 8000 words. The WSU also provides 2000 18-bit words of data memory (DM) for PROCON access. Sixteen bits of each DM word contain data, and the remaining two bits are used for parity.

The PROCON output is linked to a 16-bit data bus, which connects it to all peripherals, both within the DF and in other cell-site frames.

Separate control signals from the PROCON indicate the address of the peripheral to be connected to the data bus to receive a particular message. In a similar manner, peripherals are connected to the data bus to allow the controller to read information from a peripheral's output register when the peripheral is acting as a sensor. Parity is added at the source for all data messages placed on the bus and is checked by the unit receiving the message before it is used.

2.3 Setup radio communication

Setup radios, as described in Ref. 1, transmit only data, and are used in the initial phase of "setting up" the call prior to the establishment of a voice path for communication. They are for the general (shared) use of the cell site in communicating with all mobiles within its zone. In addition, the setup radios also transmit overhead messages to assure that idle mobiles within the cell coverage zone are ready and able to communicate should a call be initiated to or from the mobile.

In the forward direction (land to mobile), referred to as the forward setup channel, messages may be either one or two words in length. Each word consists of data bits transmitted serially at a rate of 10 kb/s and encoded before transmission to provide 28 message bits and 12 BCH error detection/correction bits for a total of 40 bits per word. In the reverse setup direction, the mobile transmits—at the same data rate—48-bit words, with 36 of these bits available for message information and 12 bits used for the error detection/correction code. The words in the reverse direction vary in number. The number of words needed is transmitted as part of the message information. In each direction, each word is repeated five times to allow a majority voting of the detected word to protect the integrity of the transmission against the effects of noise, multipath fading, and interference. To minimize the effects of noise that comes in bursts, the five repeats of each message in the forward direction are interleaved with similar messages addressed to another mobile. This group of two words, each transmitted five times, is preceded by 10 bits of dotting (alternate ones and zeros) for bit synchronization and 11 bits of Barker Code* for word synchronization (see Fig. 6). The bit-and-word synchronization permits the mobiles to frame the forward setup messages and determines when each word and each sequence of the five-word repeats begin and end. Each mobile will look at only one of the two interleaved sets of words in the message stream, depending on whether the last digit of the mobile's telephone number is odd or even.

An additional bit, called the busy-idle bit, is inserted immediately following the bit sync, the word sync, and every 10 bits of each message word. If the bit is a 1, the reverse setup channel of the particular cell

* Barker Code consists of a bit sequence that is highly unlikely to be reproduced by rhythmic or random noise. It is 11100010010.

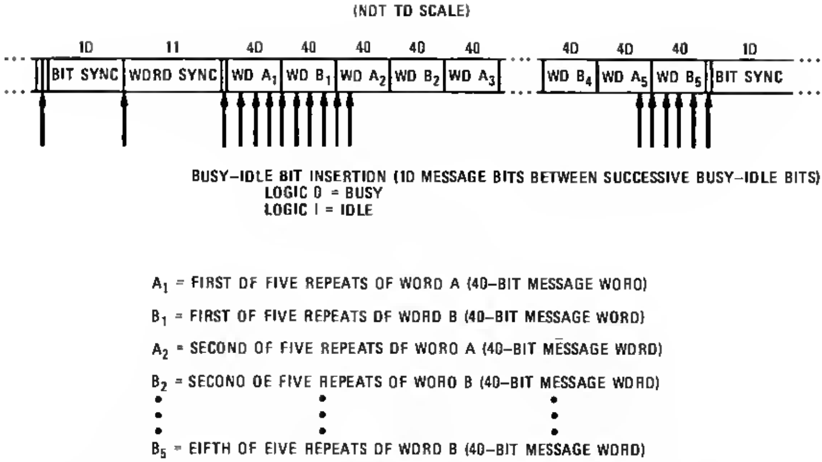


Fig. 6—Forward set-up channel message stream. A given logic unit reads only one of the two interleaved messages.

site transmitting the message stream is idle, and any mobile desiring to initiate a call or to respond to a page may transmit. If the bit is a 0, the reverse setup channel is being used by another mobile transmitting a call origination or a page response. A mobile wishing to transmit on that channel must wait a short time interval and monitor the channel again until idle bits are observed.

There is no essential difference between a voice radio and a setup radio, *per se*. In fact, the identical radio equipment codes may be used in either position. The differences in practice between the setup radio and the voice radio are the frequency channel to which each is assigned and the interface circuits that control the operation of the radio.

In the case of the setup radio transmitter, four circuit packs,* three designated as setup transmitter interface and one as setup transmitter controller, take the information from the controller and prepare it in a form appropriate to sending the data message over the setup channel. The three setup transmitter-interface packs behave as one functional unit. They latch and hold the data received from the controller, determine the appropriate time to load this word into a shift register, check the word for parity, inhibit the transmission of a word if parity does not check properly, shift the data out of the register one bit at a time to convert the word from parallel to serial form, and convert the data into Manchester coding.† The setup transmitter controller determines which of the setup radios will be used on line and which will be retained as the redundant spare. The setup transmitter controller has the capability of controlling up to five setup radio transmitters. In the Chicago developmental system, however, the anticipated traffic levels

* The physical design of these circuit packages is discussed in Section 7.2.
† See Ref. 2 for a discussion of Manchester coding.

during the equipment and service tests will not require more than one set-up transmitter and one spare.

2.4 Locating radios

To maintain signal strength sufficient for good-quality voice and data transmission, each mobile must communicate with an appropriately located cell site within tbe MSA. When a call is initially set up, locating the appropriate cell site is done by the mobile as it scans all setup channels and selects the one with the highest signal level for use in transmitting the reverse setup messages. After the call has been established, the mobile may move out of the area of sufficient signal strength. It then becomes necessary to route the call through another cell site whose location provides better signal quality to that mobile. Reference 1 describes how the system implements a handoff.

After the handoff event bas been completed, the call continues until another handoff is required or until either party terminates the call.

To determine when and if a handoff is necessary, locating measurements are made once every few seconds on each active voice channel. Two techniques for locating are provided in the AMPS systems. The primary method is signal-strength measurement. The alternate method is called phase-ranging and is described in Section III.

Signal measurements for locating are performed by equipment consisting of a locating radio receiver (LRR), a tunable synthesizer, and a locating receiver interface (LRI). There are four LRRS with their associated synthesizers and interface circuit packs per cell site. Three sets are required to handle the busy-hour traffic load. The fourth is a spare to assure maintenance of service by reconfiguration should any of the on-line equipment become defective.

The cell-site controller (Section 2.2) keeps track of all calls which the cell is serving and makes a locating measurement on each call every few seconds. The controller sends, via the data bus to the LRI, a message containing a 10-bit binary number representing the channel code. The LRI then directs the associated synthesizer to tune its local oscillator to the frequency of the selected channel. The LRR develops an output voltage which is a function of the carrier signal quality. After a period of time to allow for settling, this voltage is held fixed by a track-and-hold circuit, while an analog-to-digital converter in the LRI converts the voltage representing an input signal range between −110 and −30 dBm into an 8-bit binary number and places it in the output register. Concurrently, a "Ready Output flag" is set to signal the controller that the measurement is available for readout. Because the controller has stored the channel number for which the measurement request was made, it is unnecessary to include any channel identification in the output word. Only the signal strength value is returned to the controller.

The MTSO considers voice channel signal quality information from the controllers in the serving cell and in adjacent cells. A handoff process is initiated to transfer the mobile as it moves between cells so that it will again be served by the cell site receiving the best signal quality. The process of executing the handoff is described in Ref. 1.

2.5 Voice channel data communications

After a call has been set up, it must be monitored to determine when it is necessary to send various orders to the mobile, such as an order to turn off the mobile's transmitter at the termination of the call, or an order following a user request for one of the optional vertical services. The method of monitoring the call (referred to as call supervision) is described in Section III for all features except locating, which has been discussed above. Orders and requests for vertical services must be transmitted so as not to interfere significantly with voice conversations. They are sent in the form of binary data messages over the voice channel by momentarily muting the voice and inserting a binary data sequence, then restoring the audio capability. The data sequence requires approximately a tenth of a second. This technique, called blank-and-burst, is discussed in more detail in Refs. 1 and 2. Below is a brief summary of the method of implementing this technique.

The data messages over the voice channel in the direction from the cell site to the mobile are referred to as forward blank-and-burst. Those from the mobile to the cell site are called reverse blank-and-burst. The forward blank-and-burst order is initiated by the MTSO, which sends an appropriate message over the data link to the controller in the cell site. The controller then sends the required message to the voice transmitter data interface (VTDI), a single function spread over three circuit packs; it also directs the LSF controller to set up the required connection in the LSF between the VTDI and the voice radio channel assigned to the addressed mobile. The VTDI accepts the order from the controller in three successive parallel 16-bit words and converts them into a single 40-bit serial word that is sent at a 10-kb/s rate to the voice radio transmitter via an electronically switched connection in the Line Supervision Frame (LSF). The message format is shown in Fig. 7. The VTDI also precedes the data word with the bit sync and the word sync and repeats this grouping of bit sync, word sync, and the 40-bit data word 11 times before the LSF restores the channel to the voice mode. The use of 11 repeats ensures that there will be a sufficient number of properly received words to permit accurate word decoding by the mobile's logic unit in the noisy or interference-limited environment of AMPS.

If the mobile customer has subscribed to vertical service features, his request for a specific vertical service (such as third-party add-on to a call) must be transmitted as a data word via the blank-and-burst

technique. The implementation of blank-and-burst in the reverse direction (mobile to cell site) is somewhat different from that of the forward direction.

The customer initiates his request for vertical service by entering a specific number sequence (including the telephone number of a third party, if applicable) via the *TOUCH-TONE®* calling pad into a register within the mobile logic unit. Then the customer depresses the SEND button* which is analogous to operating the switch-hook to obtain an operator's attention. The SEND button causes the signalling tone (ST)† to be transmitted over the voice channel for about 0.5 second. The LSF, recognizing that a signaling tone has been detected, operates a relay on the trunk switching unit to put the trunk into the on-hook state. When the MTSO, which monitors the on-hook, off-hook condition of each trunk, detects an on-hook condition of 0.5-second duration, it sends a message to the cell site telling the requesting voice channel to transmit data.

The voice receiver data (VRD) group in the data frame consists of a voice receiver data radio, a tunable frequency synthesizer, two interfacing circuit packs, and a data modem consisting of four circuit packs (clock initialization, clock acquisition system, Barker sequence detector and bit decoder, and majority voter). One VRD group is used for the entire cell site because traffic levels on it are expected to be low and the messages handled are not time-critical. It is backed up by a redundant spare. The working VRD must be tuned, therefore, to the frequency of the channel expecting a reverse blank-and-burst message. Upon receipt of the MTSO message indicating the channel number of a mobile that had "flashed," the PROCON orders the synthesizer associated with the data receiver to tune to the designated channel. When the PROCON detects the "in lock" flag (which indicates tuning is complete), it orders a forward blank-and-burst message to be sent to that mobile directing it to transmit a reverse blank-and-burst message. The mobile then transmits over the voice channel the data message corresponding to the request which the customer had initiated via the *TOUCH-TONE* calling pad and SEND button.

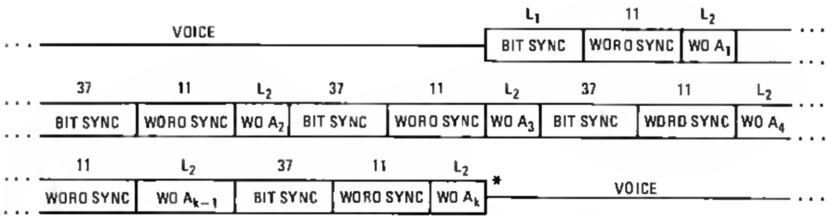
The reverse blank-and-burst message format is diagrammed in Fig. 7 and consists of 100 bits of "dotting" bit sync (alternate 1s and 0s), 11 bits of word sync (Barker code), and 48 bits of message data, of which 36 are information bits and 12 are error-detecting/correcting bits. This grouping of bit sync, word sync, and message is repeated four more times, for a total of five consecutive transmissions, except that in the last four the bit sync is limited to 37 bits of dotting rather than 100. The Barker sequence detection and bit decoder, the clock initialization,

* Other features of the SEND button are discussed in Ref. 3.

† The signaling tone is an out-of-voice-band 10-kHz tone detectable within the LSF. The function of the signaling tone and the operation of the LSF in detecting various states of the call are discussed in Section III.

and the clock acquisition system circuit packs detect the dotting and develop from it a clock signal synchronized with the clock in the mobile to facilitate detection of the Barker code and the data message.

The five transmissions of the message are each delayed within the majority voter shift registers long enough to cause them to enter the bit summing network (voter) in bit synchronism as shown in Fig. 8. As a result, a voted output occurs, one bit at a time, according to the detected value of each bit that occurred on at least three of the five



LEGEND

SYMBOL	FORWARD DIRECTION	REVERSE DIRECTION
K	11 REPEATS	5 REPEATS
L_1	100 BITS	101 BITS
L_2	40 BITS	48 BITS

* IN REVERSE DIRECTION A SECOND MESSAGE (B) MAY FOLLOW WD A_k.

† FORWARD DIRECTION IS FROM THE CELL SITE TO THE MOBILE. REVERSE DIRECTION IS FROM THE MOBILE TO THE CELL SITE.

Fig. 7—Voice channel data message formats.

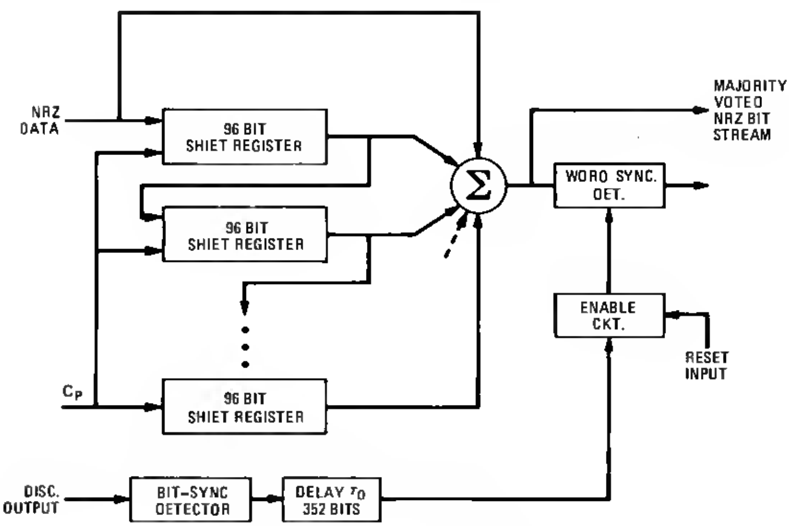


Fig. 8—Majority voting system.

transmissions. This word, made up of majority voted bits, is then converted in an interface circuit pack from a 48-bit serial word to three successive 16-bit parallel words and sent over the data bus to the PROCON. The PROCON tests the BCH error detection/correction coding, reformats the message, and sends the information over the data link to the MTSO. The MTSO performs the necessary actions to comply with the customer's request for a vertical service. The customer's request is received by the MTSO within a second after the "flash" message is received at the cell site.

III. LINE SUPERVISION FRAME

The line supervision frame (LSF), shown in Fig. 9, provides the perchannel audio-level speech-path interface between the MTSO-controlled telephone trunk network and the radio frame that transmits the radio frequency voice communication to and from the mobile unit. In addition to this principal function, the LSF also performs the following system functions:

(*i*) Enables transmission of forward blank-and-burst data messages by connecting the VTDI circuits to the appropriate voice transmitter.

(*ii*) Provides line supervision and control through monitoring of the supervisory audio tone (SAT) and the signaling tone.

(*iii*) Turns transmitters and receivers on and off as requested by the MTSO via the DF according to the level of mobile telephone traffic.

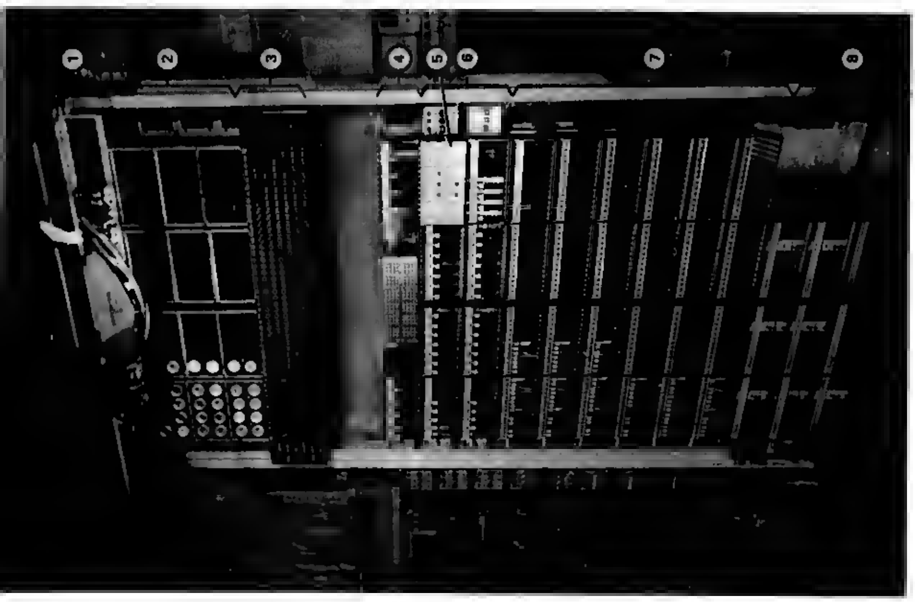
(*iv*) Provides range measurements on each mobile by measuring the phase delay of the received SAT.

(*v*) Enables voice trunk maintenance tests to be performed by switching trunks into loop-back configurations.

The audio circuits in the LSF are supplied in modules. Thus, a single LSF can support from 1 to 48 separate voice channels. As many as three LSFS can be connected to a single DF, allowing the maximum capacity of a cell site to be 144 voice channels.

The LSF has two functional parts: the voice channel circuits and the frame controller. The voice channel circuits are modular; the quantity supplied varies according to the number of voice trunks terminating in the frame. This number depends on the traffic requirements for the cells, but it cannot exceed 48 in a single LSF. The controller is installed complete, with redundancy, independent of the number of trunks terminating in the frame.

Each voice channel circuit consists of a group of eight printed circuit boards and six jacks used for testing and monitoring the trunk/voice channel circuits and the voice channel circuits/voice radio interfaces.



1. INTERCONNECTION PANEL
2. TRUNK SWITCHING UNIT PANEL
3. JACK PANEL ASSEMBLY
4. SAT DISTRIBUTION PANEL
5. LSF DISPLAY UNIT
6. LSF CONTROL UNIT
7. VOICE CHANNEL CIRCUIT PANEL
8. CONVERTER PANEL

Fig. 9—Line supervision frame.

3.1 Voice chennel circuits

The voice channel circuit performs all the baseband signal processing for a single voice radio. Before the transceiver baseband signals can interface with the telephone network, certain control signals must be added on the transmitter path, and other control signals must be removed from the receiver path. To obtain these control signals, each line circuit has access to several busses carrying both analog and digital information. Each line circuit is permanently wired to the 6-kHz supervisory audio tone (SAT) bus and to the 10-kHz clock bus. Access to the trunk-maintenance bus, serial-data bus, and phase-range bus is controlled by signals from the LSF controller. The state of each line circuit is indicated by a group of status signals that may be read by the LSF controller. The five status signals are: (*i*) transmitter power on/off, (*ii*) maintenance relay state (normal or loop-around), (*iii*) line control logic fade timing, (*iv*) line control logic timed out, and (*v*) off-hook. Each line circuit contains a logic circuit that controls dc line supervision on the MTSO-cell-site path and shuts off the cell-site transmitter if mobile-to-cell-site transmission is interrupted for more than 5.5 seconds.

The audio processing section serves to interface the four-wire, voice-grade, telephone trunks with the cell-site transceivers. A syllabic compandor reduces audio noise in the transmission system. The compandor is composed of two sections. A compressor at the transmitting end reduces variations in speech input power levels by a factor of 2 (in decibels). An expandor at the receiving end performs the inverse operation. The loss of the expandor must complement the gain of the compressor so that the end-to-end relative signal levels are unaffected. The overall effect of these circuits provides an improved signal-to-noise ratio for the received speech. Both the mobile and the cell-site audio circuits must contain similar speech compressors and expandors. (See Ref. 2 for a more complete discussion.)

Figure 10 is a block diagram of the audio processing circuits. The PC7 transmit-audio compressor circuit pack contains the compressor half of the compandor circuit. The audio from the voice trunk feeds into the compressor; the compressed audio output feeds into the audio filter. The PC1 transmit-audio filter contains a sharp 300- through 3000-Hz bandpass filter, which band-limits the audio from the compressor. One of the three possible cell-site SAT frequencies* is selected at the SAT cross-connect panel, added at the output of the low-pass filter, and combined with the audio signal in an operational amplifier summing circuit. The output is the composite audio and SAT signal, which is passed through the data/voice switch in the PC2 bit encoder

* 5970, 6000, or 6030 Hz.

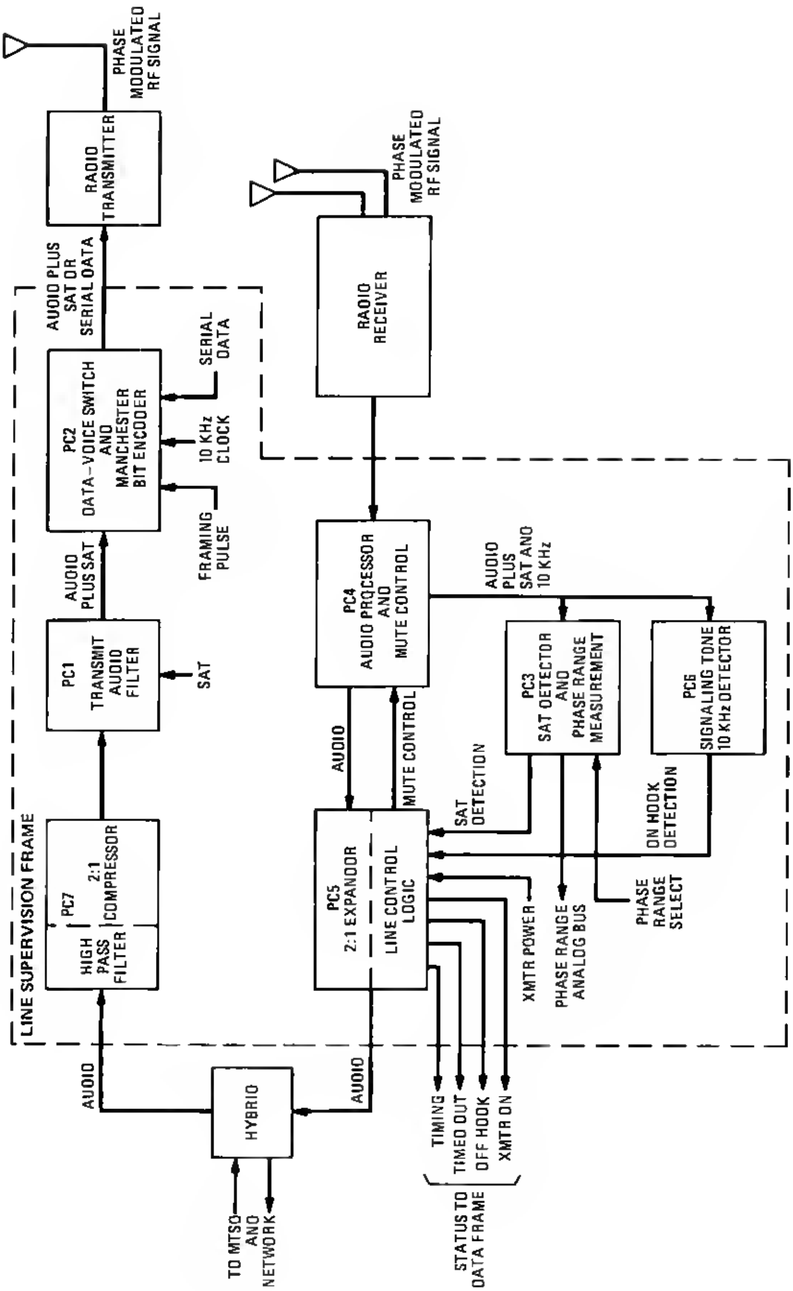


Fig. 10—Audio processing circuit.

and data-voice switch to the transmitter in the radio frame when the switch is in normal or voice position.

When the cell site must send short bursts of high-speed data (during the time the mobile is tuned to the voice channel), it uses the blank-and-burst mode. While data are being sent, a framing pulse switches the data-voice switch to the data mode. The framing pulse inhibits the audio, selects for use one of the two redundant data busses, disconnects the voice transmitter from the audio system, and connects it to the signaling system bit encoder. Serial data from the selected data bus are gated into the Manchester encoder. The data and the 10-kHz clock are exclusively NOR-gated to give a Manchester-encoded format. The data then pass through a Bessel shaping-filter, which removes the high-frequency components. The serial data message, Manchester-encoded, is then passed to the transmitter in the radio frame and transmitted to the mobile. See Ref. 5 for more details on data transmission.

Communications in the otber direction—from the mobile—are received by the associated voice receiver in the radio frame. These signals contain audio plus the SAT and on occasion the 10-kHz signaling tone (ST). While data in the form of blank and burst messages are also sent from the mobile over the voice channel, those messages are not processed through the voice radios or the line supervision frame. Instead, they are received by the voice data radio receiver in the data frame and processed through its associated modem.

The output of the voice receiver's discriminator is sent to the PC4 receive audio processor, basically a combination bandpass filter and frequency modulation de-emphasis filter. The overall transfer characteristic is a 6-dB/octave slope in the voiceband and a sharp 24-dB/octave fall-off in the region outside the voiceband. The output is fed to the audio expandor circuit. An output ahead of the filter, containing the SAT and the 10-kHz ST, is connected to the SAT and ST detectors, respectively. The audio expandor circuit is mounted on the PC5 line control circuit card. The input to the expandor is from the PC4 receive audio processor circuit pack and the output is connected to the operating company voice trunk.

In addition to the expandor circuit, the PC5 line control circuit contains logic to detect the voice channel status, to control the on/off status of the voice transmitter and receiver, and to transmit status indications to the data frame controller. Voice channel status is developed from the transmitter power array in the LSF controller (see Section 3.3) and from the outputs of the SAT and ST detectors for the following status reports: timing, timed out, off-hook, and transmitter power on. The transmitter is turned off to prevent radiation of power on any channel not in use. Similarly, the receiver is disconnected from

the trunk to prevent receiver noise (which is maximum in the absence of a detected carrier) from entering the land line trunk when the channel is unoccupied. The muting circuits to disconnect the receiver from the trunk are located in PC4.

The SAT, which is added to the transmitter baseband signal at the output of the audio bandpass filter, is transponded at the mobile and detected in PC3 of the cell-site receiver signaling system. It monitors the continuity of the cell-site-to-mobile path and furnishes ranging information. The SAT detector output is at logic 1 as long as the correct SAT frequency is detected and the carrier-to-noise ratio is greater than 7 dB. If SAT is not detected, the line control goes into a timing condition. If recovery is not made in 5.5 seconds, the call is considered lost and the circuit will time out and shut off the cell-site transmitter.

A phase-locked loop detector performs an estimate of the distance between the cell site and the mobile by comparing the phase of the transmitted and received SAT signals. The mobile-to-cell-site distance is a linear function of this phase difference. The difference in phase is converted into a dc analog signal, which is connected via the phase-range switch and the phase-range bus to an analog-to-digital converter in the LSF controller.

The mobile may autonomously transmit a 10-kHz signaling tone as part of its disconnect sequence or as an acknowledgment of the receipt of certain orders. The PC6 contains a detector circuit, which is an active 10-kHz (ST) bandpass filter followed by a full-wave rectifier, low-pass filter, and level comparator. The ST output is a logic 1 when the tone is present. It is fed to the PC5 line control circuit. The line control circuit monitors both the SAT and ST logic outputs generated by the tone detectors in the signaling system and uses them to control the DC supervision current (off-hook signal) in the MTSO to cell-site trunk and the transmitter on-off status. When the mobile party disconnects, the mobile sends the 1.1-s, 10-kHz ST. The line control circuit, via control of the trunk switching unit, removes the off-hook signal from the land trunk. The MTSO detects the trunk on-hook transition and sends a blank and burst release order to the mobile to shut off its transmitter.

For maintenance aids, the voice trunks from the MTSO connect to a set of test jacks for each trunk. There are six jacks per trunk:

(*i*) Transmitter network out: Disconnects the trunk and connects to trunk output.

(*ii*) Transmitter compressor in: Disconnects the trunk and connects to the audio compressor input.

(*iii*) Transmitter monitor: Monitors the transmit trunk.

(*iv*) Receiver network in: Disconnects the trunk and connects to the trunk input.

(*v*) Receiver out: Disconnects the trunk and connects to audio processor output.
(*vi*) Receiver monitor: Monitors the receive trunk.

3.2 Trunk switching unit

The trunk switching unit (TSU) consists of the trunk maintenance switch and the loop signaling switch for one trunk. It contains two relays mounted on a printed circuit board. In the normal state, each trunk connects through its TSU to its associated audio processor. The maintenance relay signal from the LSF controller operates the maintenance relay to disconnect the trunk from the audio processors and connect it to the test trunk. A maintenance relay status signal is returned to the LSF controller to indicate that the relay has operated. The off-hook signal from the line control circuit operates the second relay to provide a closure for the loop signal current to operating company equipment.

3.3 Line supervision frame controller

The LSF controller receives data words from the DF cell-site controllers and examines each word to determine the voice circuit to be accessed and the function to be performed. The LSF controller consists entirely of wired logic and contains redundant circuitry, designated side A and side B. Each side may accept data words from either cell-site controller, the choice being determined by the load signal used. Both sides can access any of the voice circuits. A block diagram of one side of the LSF controller is shown in Fig. 11. To avoid complexity, this figure omits all interactions with the redundant side.

The transmitter power control circuit consists of two array access circuit packs, one for each side of the LSF controller, and two transmitter power array circuit packs, which are common to both sides of the controller. The array access circuit pack contains the control to set and reset the selected flip-flop in a 48-element array contained in the two transmitter power array circuit packs. The inputs consist of the radio address, the frame address, and the transmitter-on and transmitter-off signals. The output controls the on/off state of each voice transmitter and is sent to the transmitter via its associated PC5 line control circuit.

The maintenance selector circuit is similar to the power control circuit. It consists of two array access circuit packs, one on each side of the LSF controller, and two maintenance array circuit packs which are common to both sides of the controller. The maintenance array consists of 48 flip-flops that are set or reset by signals from the array access circuits. The outputs go to the 48-trunk switching units to operate the maintenance relays.

The data/voice selector consists of a demultiplexer circuit pack on each side of the LSF controller. Its purpose is to select the voice channel

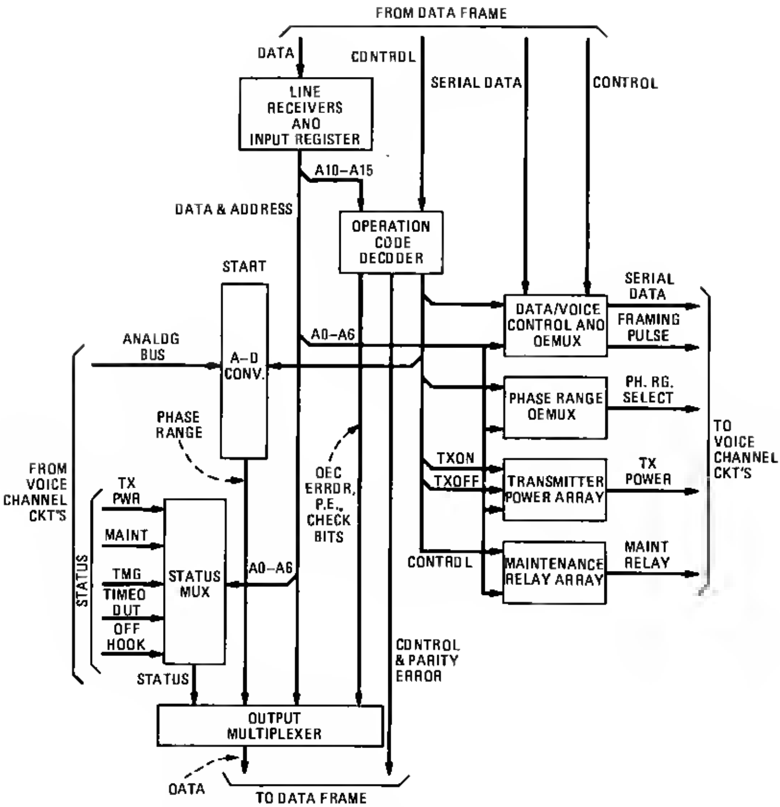
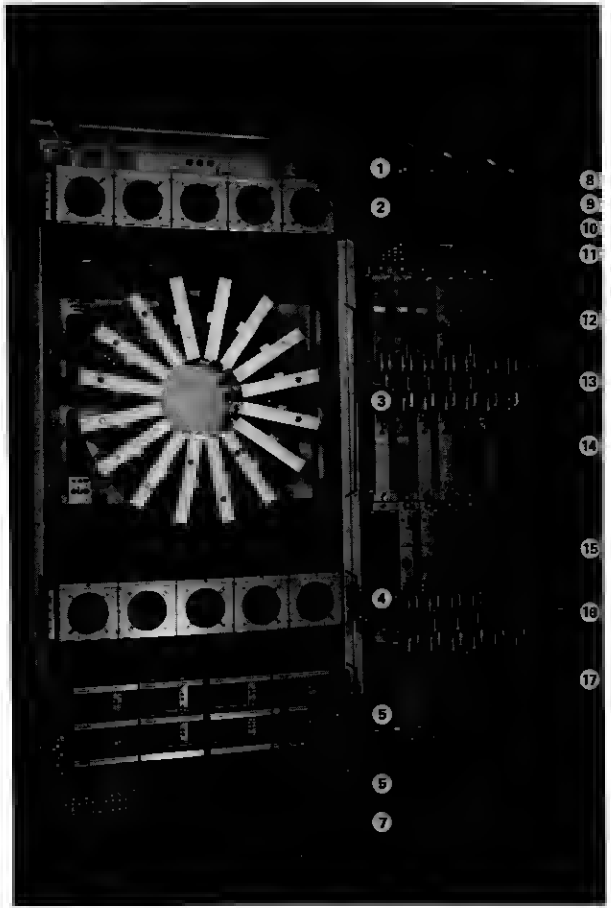


Fig. 11—Line supervision frame controller block diagram.

and control the flow of serial data for the forward blank-and-burst function. The data/voice selector contains an eight-bit register to store the radio address, the frame address, and the VTDI select bit. The VTDI select bit chooses the voice transmitter data interface it will use as the serial data and framing pulse source. The selected serial data are placed on a bus that drives all the bit encoder and data voice switches in the 48 voice circuits. The address output of the register is used to drive the data voice demultiplexer. It is a 1-out-of-48 decoder, which delivers the framing pulse to the selected bit encoder and data voice switch that receive the serial data.

The phase-range selector circuit consists of a phase-range demultiplexer circuit pack in each side of the LSF controller. The phase-range demultiplexer is a 1-out-of-48 decoder, which receives the radio and frame address from the input register and is enabled by the set phase-range switch signal from the operation code decoder. The analog-to-digital converters change the phase-range analog-voltage output of the phase-ranging circuit to an eight-bit binary code, which is transmitted to the cell-site controller.



AMPLIFIER COMBINER BAY

KEY	NAME
1	INTERCONNECTION PANEL
2	POWER AMPLIFIER ASSEMBLY INCLUDES 8 POWER AMPLIFIER MODULES
3	CAVITY COMBINER (CHANNEL MULTIPLEXER) ASSEMBLY
4	POWER AMPLIFIER ASSEMBLY INCLUDES 8 POWER AMPLIFIER MODULES
5	POWER CONVERTER PANEL
6	FUSE MOUNTING PANEL
7	POWER FILTER PANEL

TRANSCEIVER BAY

KEY	NAME
8	INTERCONNECTION PANEL
9	RF DIVIDER PANEL
10	JACK PANEL ASSEMBLY
11	RADIO CONTROL CIRCUIT PANEL
12	TRANSMITTER TRAY ASSEMBLY INCLUDES 8 CHANNEL TRANSMITTER MODULES
13	RF DISTRIBUTION PANEL
14	RECEIVER TRAY ASSEMBLY INCLUDES 8 RECEIVER MODULES
15	TRANSMITTER TRAY ASSEMBLY INCLUDES 8 CHANNEL TRANSMITTER MODULES
16	RF DISTRIBUTION PANEL
17	RECEIVER TRAY ASSEMBLY INCLUDES 8 RECEIVER MODULES

Fig. 12—Typical radio frame, equipped with 16 voice channels.

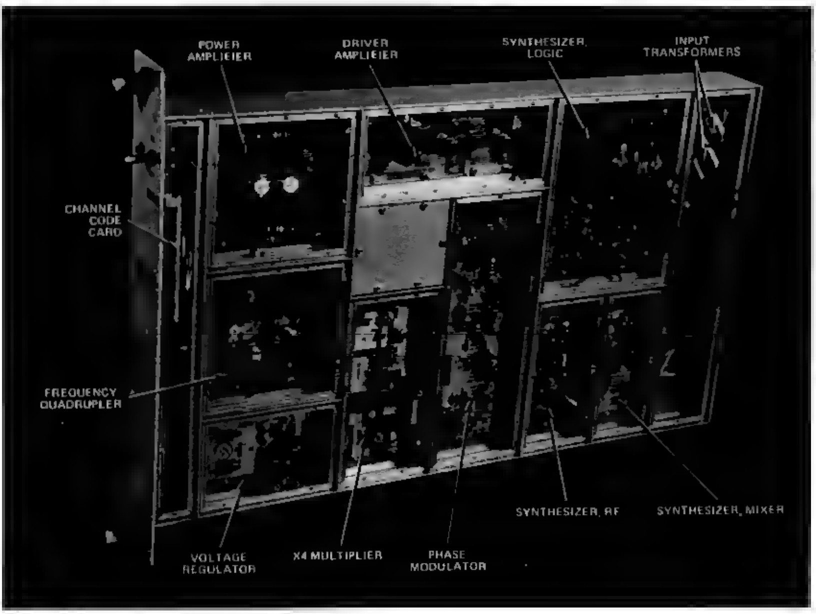


Fig. 13—Typical channel transmitter module unit with covers removed.

IV. RADIO FRAME

4.1 Overview

Figure 12 is a photograph of a 16-channel radio frame.*[4] As stated earlier, each radio frame is composed of two bays. The transceiver (TR) bay contains 16 pairs of voice channel transmitters and receivers. A companion power amplifier/combiner (PA/C) bay amplifies and combines the outputs of the voice transmitters.

The radio frame interfaces with the radio transmission environment through three antennas: one for transmit, the others for two-branch space-diversity receive. When the cell site equipment is configured for omnidirectional coverage, these antennas are omnidirectional (in the azimuthal plane) with 10-dB gain. Alternatively, when the cell site functions in the directional mode, one radio frame services each face (direction) via three 120-degree directional antennas each with 10-dB gain.†

The radio frame interfaces with the LSF via 16 four-wire, balanced bidirectional trunks, one servicing each voice cbannel. "Transmitter-on" control signals originate within the LSF. Finally, dc power is supplied from the +24 V battery system as described in Section VI.

Each duplex voice channel (see Fig. 12) is served by a "radio" consisting of a set of four modules located within tbe radio frame.

* When more than 16 voice radio channels are required at a cell site, additional radio frames are added.

† Additional antenna gain, easily obtained in the directional mode, is not required.

(*i*) A channel-transmitter module (see Fig. 13) produces a 1-watt carrier, which is phase-modulated by voice/SAT or frequency-modulated with 10 kb/s data provided by a transmit channel circuit within the LSF. A 666-channel frequency synthesizer, located within the transmitter module, generates the correct channel frequency, which is also the local oscillator for the companion receiver.

(*ii*) A power-amplifier module (see Fig. 14) boosts the 1-watt angle modulated carrier, from the transmitter module, to 45 watts.

(*iii*) The channel multiplexer combines the 16 45-watt carriers, from the power-amplifier modules, onto one coaxial transmission line, which goes to a transmit antenna.

(*iv*) A channel-receiver module receives a two-branch diversity input derived from the two receiving antennas feeding an array of broadband amplifiers and hybrid power splitters. From these inputs and from a local oscillator signal, derived from the companion transmitter module, the receiver demodulates a baseband voice/SAT or data signal, which is delivered to a receive-channel circuit within the LSF.

A radio frame need not be fully loaded with modules; any number of sets, from 1 to 16, are used depending upon the required channel

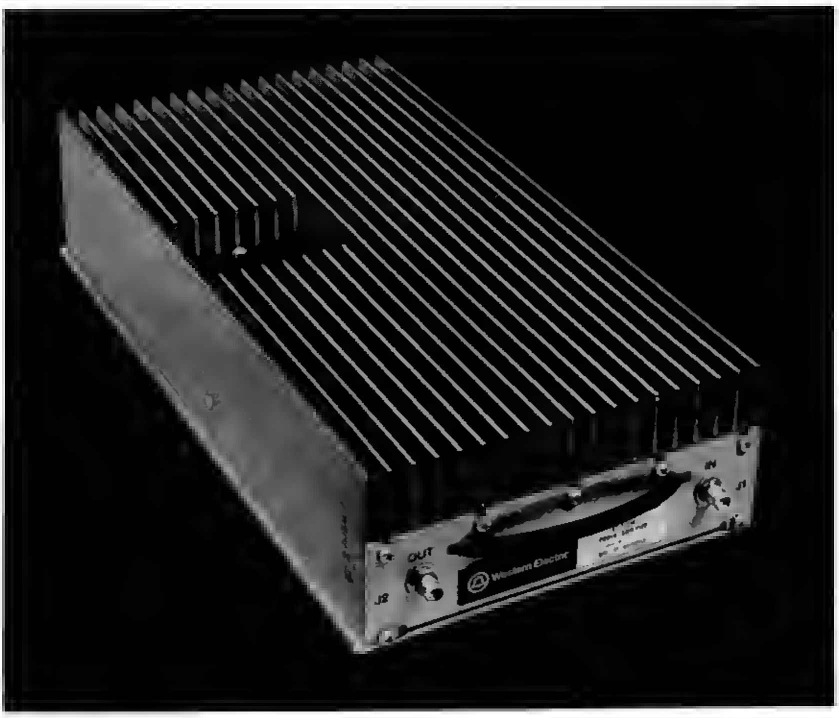


Fig. 14—Typical power amplifier module.

capacity. The channel multiplexer, as presently designed, must provide for all 16 channels; the unused inputs are terminated by 50-ohm loads. A brief design overview of each radio module follows.

4.2 Channel transmitters

Figure 15 is a block diagram of a 16-channel radio frame. The blocks marked TRAN_0 to TRAN_{15} are 1-watt output, PM voice/SAT or FM data transmitter modules. The channel frequency for each transmitter, situated in the 870- to 890-MHz band, is generated within its self-contained frequency synthesizer. A digital program plug inserted into the front panel of each transmitter module selects the desired channel. Thus, each voice transmitter resides permanently on one selected radio channel.

Figure 16 is a block diagram of the frequency synthesizer, which uses the indirect frequency synthesis method to generate any one of 666 stable carriers upon digital command from 10 parallel binary program lines. Each carrier, at one-quarter the final output frequency, is stable to within ±1 part per million over a 0°C to +40°C temperature range. A relatively unstable, varactor-tuned, voltage-controlled oscil-

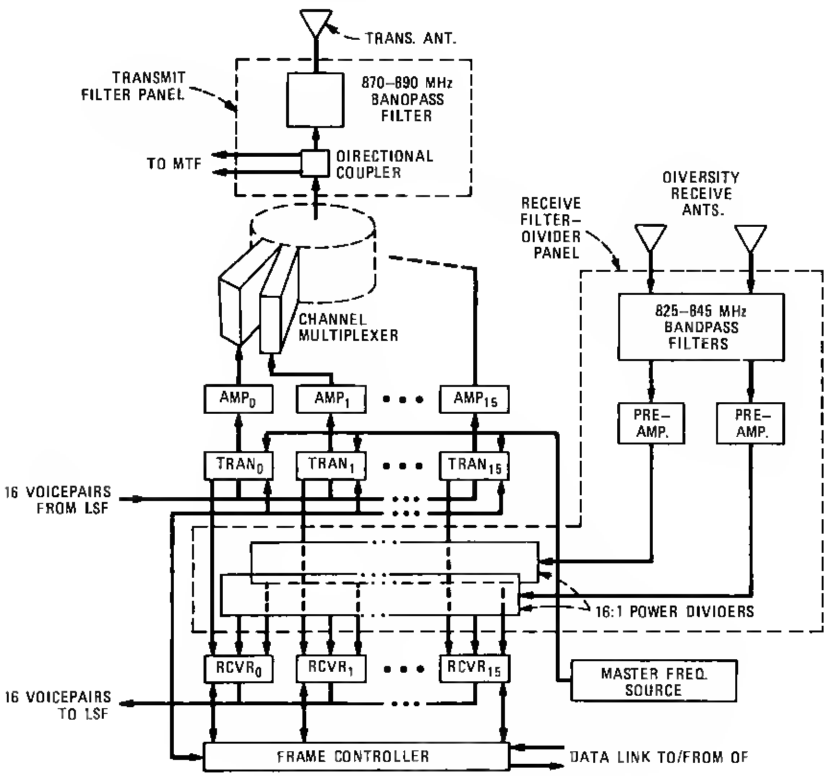


Fig. 15—Block diagram of 16-channel radio frame.

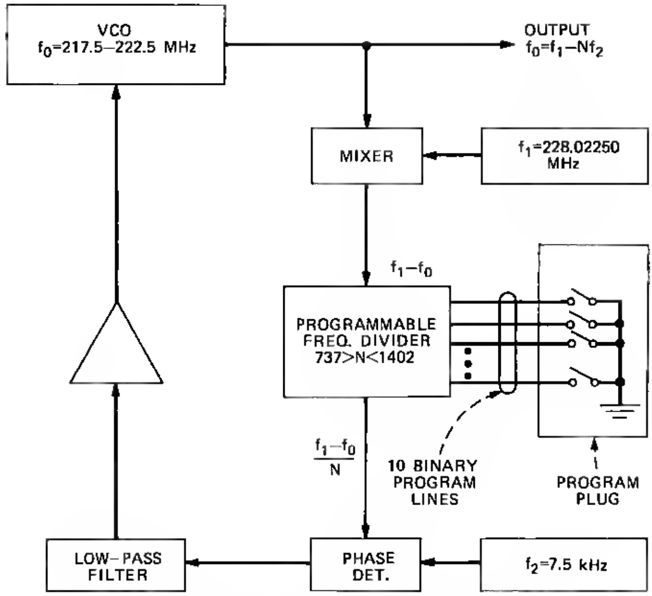


Fig. 16—AMPS cell-site frequency synthesizer.

lator (VCO) generates the synthesizer output frequency f_0. A portion of the VCO output power enters a mixer, where it is heterodyned against $f_1 = 228.02250$ MHz, which is derived from a quartz crystal-controlled oscillator located within the MTF (see Section V). The output difference frequency $f_1 - f_0$ (between 5.5 and 10.5 MHz) is "divided down" by a selected integer N, in a programmable digital frequency divider. The specific combination of dc voltages on the 10 parallel binary program lines determines the division factor N, which can range between 737 and 1402. A stable 7.500-kHz reference oscillator (f_2) is compared with the divider output frequency $[(f_1 - f_0)/N]$, nominally near 7.5 kHz, in the phase detector. Any phase error is fed back to the VCO in the form of a dc control voltage, keeping the total loop in phase-lock. When in lock, the output frequency is given by $f_0 = f_1 - Nf_2$. Therefore, f_0 will have the same long-term frequency stability as the two stable reference oscillators f_1 and f_2, yet can be varied in integer steps of 7.5 kHz, by assigning different values to N. Since f_0 is in the 217.5- to 222.5-MHz band, which is one-quarter the output frequency, the 7.5-kHz frequency steps are multiplied to 30-kHz steps, the final channel spacing, in a subsequent ×4 frequency multiplier.

As an example of this frequency synthesis process, suppose the transmitter is tuned to channel 134, which is centered at 870.030 MHz. Then

$$f_0 = \frac{870.030}{4} = 217.5075 \text{ MHz},$$

and

$$f_1 - f_0 = 10.515 \text{ MHz}.$$

The division ratio is

$$N = \frac{f_1 - f_0}{f_2} = 1402;$$

thus, the frequency divider must be programmed to generate this integer.

The synthesizer output is quite pure. When the output frequency is quadrupled, the resulting audio noise in a 0.3- to 3.0-kHz band (after FM detection, deemphasis, and C-message weighting) is 40-dB below a reference 1-kHz tone with ±8-kHz peak frequency deviation.

Figure 17 shows the transmitter circuits following the frequency synthesizer. Power entering at a specified frequency in the 217.5- to 222.5-MHz band (from the frequency synthesizer) is first split, one portion going to a low-power-transistor frequency quadrupler which generates the 870- to 890-MHz local oscillator (LO) for the companion receiver. Since the LO equals the transmit frequency, the duplex-receive frequency will be 45 MHz lower (or higher) if the first intermediate frequency (IF) of the receiver is 45 MHz. For example, if a

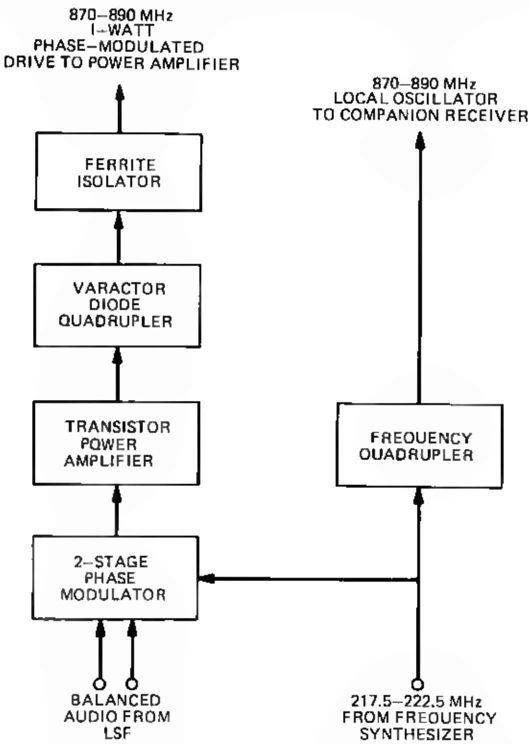


Fig. 17—AMPS cell site transmitter modulator and multiplier.

specific transmitter is programmed to transmit on channel 134, which is centered at 870.030 MHz, then its companion receiver will receive the duplex channel, located 45 MHz lower at 825.030 MHz.

The other portion of the output power (from the frequency synthesizer) enters the phase modulator, which is a two-stage, varactor-diode, reflection-type circuit. Balanced audio (or data) originating within the LSF modulates the dc bias on the varactor diodes. The modulator provides a peak phase deviation of ±12 radians (after subsequent ×4 multiplication) with less than 5-percent audio distortion.

The resultant phase-modulated carrier enters a four-stage transistor amplifier, where it is boosted to about 3 watts. This power drives a varactor-diode frequency quadrupler. After passing through a ferrite isolator, the quadrupler output appears as a 1-watt phase-modulated carrier in the 870- to 890-MHz transmit band. This output power is delivered to a companion 45-watt power amplifier located in the adjacent power amplifier/combiner frame.

4.3 Power amplifier

In Fig. 15, the blocks marked AMP_0 to AMP_{15} are Class C power amplifier modules, which boost the 1-watt input from a companion transmitter to approximately 45 watts output. The power amplifiers, which consume most of the dc power in a cell site, are designed to be powered directly from the "raw" 24-V battery supply whose voltage can vary between +21 and +28 V, depending upon the battery's state of charge. Thus, a significant cost savings is achieved by avoiding a requirement for voltage regulation of these major loads. All other equipment within the radio frame is powered from regulated (dc-to-dc converter) voltage sources.

4.4 Channel multiplexer

The 45-watt output signal from each power amplifier module is delivered into a channel multiplexer,[5,6] which is an array of 16 cavity resonators each functioning as a narrowband filter feeding a common load, the transmit antenna. The multiplexer combines these 16 signals with a maximum of 3 dB loss per channel. The minimum channel-to-channel isolation is 18 dB. Figure 18 is a photograph of the cavity multiplexer. Note that the cavities are arranged in a radial array about a 16-branch stripline feeder assembly contained within the center section. Power enters each cavity from a coaxial connector (and coupling loop) attached to the back of the cavity. The combined power exits the multiplexer by a coaxial connector connected to a "load point" at the back of the assembly. The coupling to each cavity is determined by an acceptable compromise between transmission loss and off-channel isolation. The length of each stripline to each cavity feedpoint, from the common load point, is approximately ¾ wavelength. To meet the 3-dB loss per channel, the channels are spaced

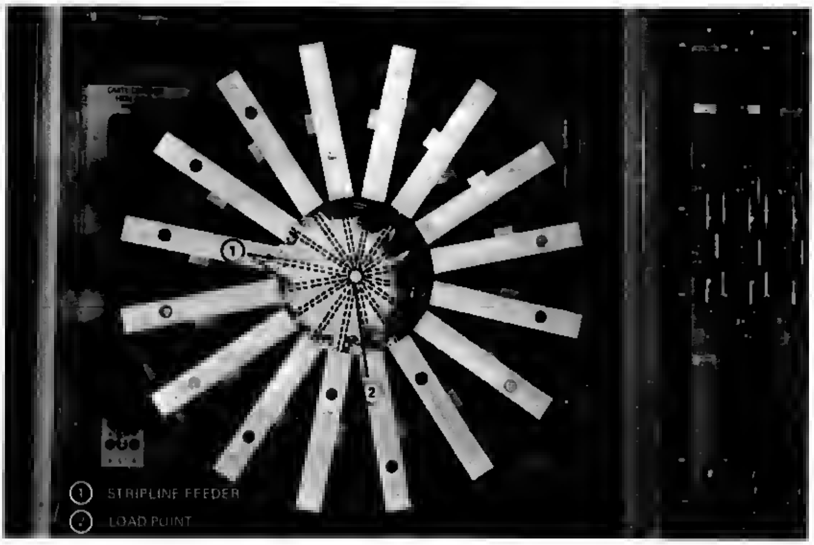


Fig. 18—Sixteen channel multiplexer.

630 kHz, or 21 channel frequencies, apart. Intermodulation is controlled by ferrite isolators, providing 30-dB reverse loss, contained within the output section of each 45-watt power amplifier. With three channels excited, the measured intermodulation products are at least 55 dB down from the desired signals.

4.5 Directional coupler post-transmit filter

The combined 16-channel group leaving the multiplexer (see Figs. 2 and 15) enters a transmit filter panel attached to the wall of the cell-site building. Here the channel group first passes through a dual directional coupler where samples (30 dB down) of the forward and reflected wave are taken. This sampled power feeds via two coaxial cables to the maintenance and test frame (Section V), where appropriate transmitter tests are made and analyzed.

Finally, the channel group passes through a low-loss, 870- to 890-MHz, bandpass filter, where out-of-band harmonics and spurious signals are removed. This interdigital filter is an eight-resonator structure that exhibits an inband loss of about 0.5 dB. The channel group reaches the antenna via a run of 1-⅝ inch o.d. coaxial cable having a loss of about 0.66 dB/100 ft.

The transmitter system is designed to provide a power of at least 10 watts per channel at the transmit antenna.

4.6 Receiver filter/preamplifier/divider

The receive signals from each of the antennas first enter the receive filter-divider panel (see Figs. 2 and 15). The arrangement of radio hardware and signal distribution on both transmit and receive ends

was conceived with a basic modularity of 16 in mind. The transmitter channel multiplexer, though providing low loss, is relatively expensive. Thus, in the receive chain, the 1-to-16 demultiplexer was chosen to be a 16-way broadband hybrid-power splitter which is low in cost but unfortunately inserts a 10 log 16 = 12-dB loss into each receive path. To recover this loss, a low-noise preamplifier (see Fig. 15) is stationed ahead of the power divider. Composed of two commercially available 25-dB gain low-noise amplifiers "parallel-coupled" via two 3-dB quadrature hybrids,[7] this preamplifier provides redundancy and also reduces by 9 dB the generation of intermodulation spurious signals. The noise figure of this amplifier-hybrid combination is 2.5 dB, and the third-order intermodulation products at the output are greater than 65 dB down from two RF signals which are −35 dBm at the input.

This UHF preamplifier is preceded by an interdigital bandpass filter giving at least 55-dB rejection to signals arriving from the 870- to 890-MHz transmit band. The total system noise figure, measured at the antenna, should not exceed 10-dB.

4.7 Receiver

Following the receive-filter preamplifier and 16:1 divider (see Fig. 15) are 16 two-branch diversity receivers labeled $RCVR_0$ to $RCVR_{15}$.

Figure 19 shows a detailed block diagram of the receiver module. The RF receive band is 825 to 845 MHz. The transmit and receive frequencies are separated by 45 MHz, and the frequency synthesized for each transmit channel is used as the first conversion local oscillator frequency in the receiver. The voice receiver noise figure is about 11-dB. A two-resonator 825- to 845-MHz bandpass filter in the feed to each voice-receiver module prevents leakage of LO out of each module into other modules and helps suppress the "half-IF" response in Mixer A. The half-IF response results from the second harmonic of an incoming signal beating against the second harmonic of the mixer's local oscillator signal. For such a response to fall at the IF frequency, the incoming signal must be displaced, in frequency, one-half the IF frequency away from the local oscillator frequency.

In the voice-receiver module, the channel to be detected is first mixed down to 45 MHz in Mixer A, which is a Schottky-diode, single-balanced mixer. The conversion loss is about 6 dB. A PIN diode attenuator, ahead of Mixer A, is driven by an automatic gain control (AGC) bus and provides up to 40-dB of attenuation. This reduces the dynamic range of the signals entering the diversity combiner. A one-stage, 12-dB gain, 45-MHz IF amplifier with a two-resonator, 30-kHz bandwidth, quartz-crystal filter at both its input and output performs preliminary channel filtering.

The 45-MHz first IF is next down-converted to a 1.8-MHz second IF by Mixer B, a balanced FET type, which is driven by a 43.2-MHz

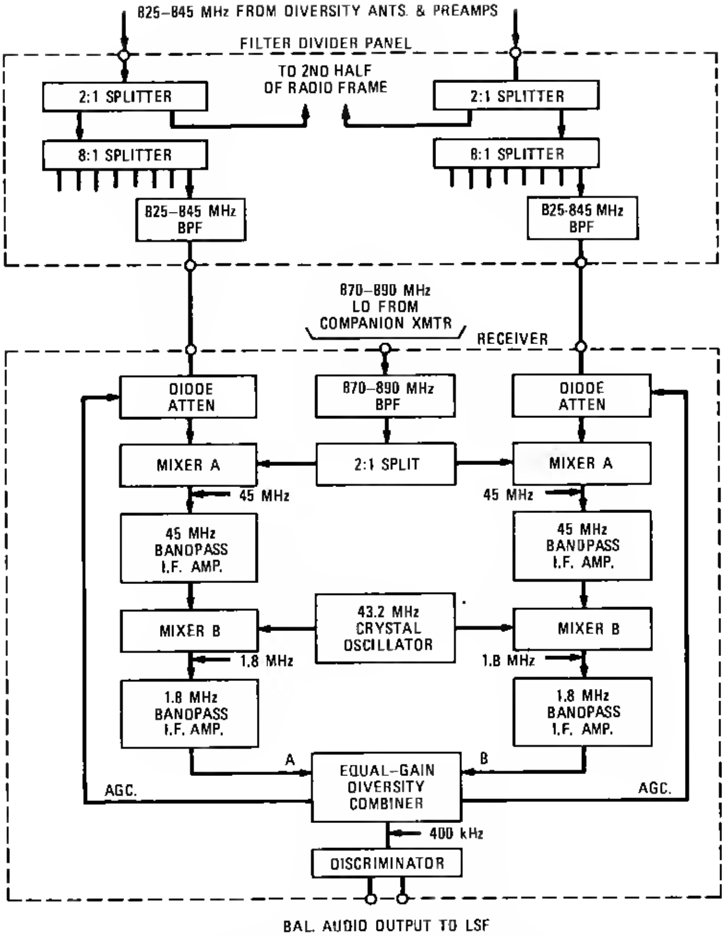


Fig. 19—AMPS cell-site voice receiver block diagram.

crystal-controlled second local oscillator. A 1.8-MHz IF amplifier with a two-resonator, 30-kHz bandwidth, L-C (inductor-capacitor) filter at both input and output performs final channel filtering. The combined gain of the second mixer and 1.8-MHz IF amplifier is about 43 dB, which is adjustable. The overall frequency response of the voice receiver is essentially eight-pole* (eight-resonator), with four poles resulting from the 45-MHz quartz-crystal filters and four poles from the L-C double-tuned circuits in the 1.8-MHz section of the IF amplifier.

The second IF frequency was made as low as the first IF image rejection would permit to simplify the design of the diversity combiner.

The two-branch, equal-gain diversity combiner uses a technique

* Eight poles appear in the low-pass prototype of this eight-resonator filter.

originally proposed by Granlund.[8] The complete theory of operation of this system has been described by Halpern[9] and Jakes[10]; a simplified explanation is presented in the appendix to this paper.

The practical limitations in the combiner design have resulted in its having a dynamic range of 50 dB. The gain and AGC in the mixer/IF were determined to suit these limitations.

The 400-kHz output signal from the diversity combiner enters a conventional limiter and a "quadrature coil" discriminator, both contained in one integrated-circuit package. The resulting baseband audio/SAT or data are then delivered over a balanced line to a receiver voice channel circuit in the LSF.

V. MAINTENANCE AND TEST FRAME

The MTF (see Fig. 20) contains the oscillators and frequency dividers to generate the master clock signals and the SAT for other equipment in the cell site. It also permits testing of the cell-site radios, the associated RF transmission circuits, and the voice trunks connecting the cell site to the MTSO.

The frame is digitally controlled by the maintenance test frame controller (MTFC), which is operated as a peripheral unit to the cell-site controller located on the DF. The MTFC's main function is to interface the cell-site controller with the various circuits and test instruments on the MTF. There is also a manual capability of loading commands into the MTFC locally, independently of the cell-site controller.

The MTF makes it possible to monitor the functioning of the cell site under the overall direction of the MTSO. When a local failure occurs, the MTF furnishes the information necessary to "maintenance busy" a faulty voice channel, or to reconfigure active and redundant circuits for maintaining service while a craftsperson goes to the cell site to replace the faulty unit.

5.1 Oscillator section

The master oscillator set generates a high-frequency reference (228.02250 MHz) and a low-frequency reference (7.500 kHz) for all the frequency synthesizers in the cell site (see Section 4.2). The 228-MHz oscillator is crystal-controlled and enclosed in a temperature-controlled oven. It has a frequency stability of ± 1 part per million per year. The frequency is distributed via coaxial cable to all radios in the radio frames and in the DF, and to the test synthesizer within the MTF. Thus, individual precise frequency sources for each of the radios are not required.

The 7.5-kHz clock signal is derived from a separate oven-controlled, 10-MHz oscillator, whose frequency is first divided by 4000 to 2.5 kHz

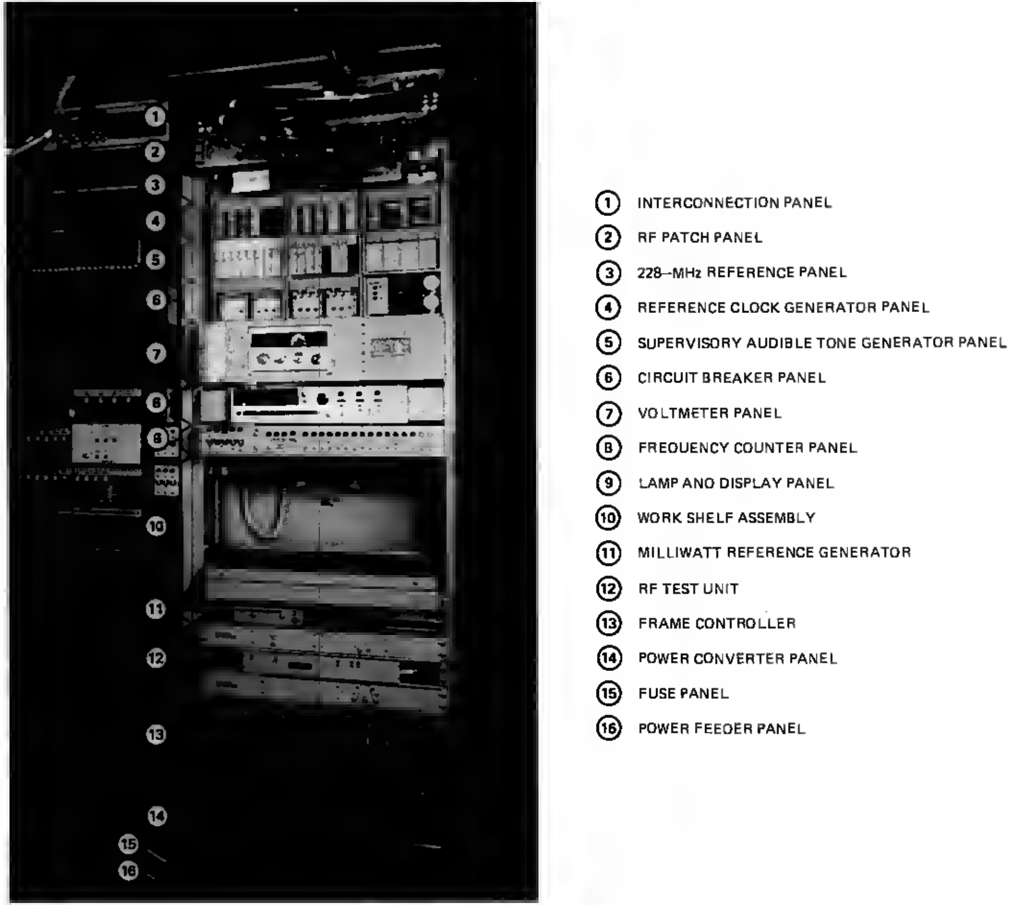


Fig. 20—Maintenance and test frame.

and then multiplied by 3. The signal is then distributed to the radios in a way similar to the 228-MHz clock signal distribution. The divider chain is tapped at 1 MHz for the PROCON clock and at 10 kHz for the serial data clock. A redundant master oscillator set will also be switched into operation automatically in the event of a lost output signal or a gross frequency change.

Three SAT frequencies—available at 5.97, 6.00, and 6.03 kHz—are each derived from a separate oscillator and distributed to the audio-processing circuits in the LSF. The 22-Hz (nominal) clock is generated by dividing the 10-kHz data clock by 456 to obtain 21.93 Hz and then sent to the LSF for use in fade time-out measurements. All clocks are redundant and can be tested by the counter within the MTF.

5.2 Test equipment

The MTF radio test equipment consists of a test receiver tunable to any transmitter channel and a test generator tunable to any receiver channel. A test frequency synthesizer for channel tuning and a test audio processor, in conjunction with the test radios, furnish controlled simulation of a mobile transceiver. There are also a digital voltmeter and a counter, both remotely controllable, and a standard 1-milliwatt, 1000-Hz reference oscillator. These units can isolate a trouble condition in the cell site, via remote control from the MTSO, to a single radio transmitting or receiving channel (or group of channels). The channel can then be shut down and a craftsperson sent to replace or repair any faulty unit of the channel.

The test receiver measures the appropriate signals to compute the following parameters of each transmitter channel for comparison against specified maintenance limits:

(*i*) Incident power to the antenna.
(*ii*) Reflected power from the antenna.
(*iii*) Transmitter frequency.
(*iv*) Transmitter deviation.
(*v*) Modulation quality (SINAD*).

The test generator injects known signals to allow measurement of the following parameters for each dual-diversity receiving channel:

(*i*) Sensitivity (noise quieting with a low-level RF input).
(*ii*) Audio output quality at an RF input above threshold.

5.3 Maintenance and test frame controller

Much of the equipment in the MTF is used to facilitate remote testing of the cell-site radios, the master oscillator equipment, and the interconnecting trunks. The MTFC serves as the digital control interface

*$\text{SINAD} = \dfrac{\text{signal + noise + distortion}}{\text{noise + distortion}}$

between the cell-site controller and the MTF oscillators and test equipment. It also serves as a data interface to the various instruments on the MTF. Since most of these instruments require several seconds to complete their measurements, the MTF does the waiting and raises a flag when a sequence of measurements is completed. This saves tying up the cell-site controller in a long-wait loop.

The MTFC consists of a PROCON and a writable store unit, similar to those in the DF, and a group of logic and modem cards. The PROCON controls the operation of the test equipment in the MTF and formats and transmits the responses to each requested test measurement. It operates under the direct control of the PROCON in the DF which, in turn, is commanded by the MTSO. The logic cards provide the necessary interface buffering, while the modem, test receiver, test generator, and SAT transponder simulate the action of a mobile to permit measurements of (*i*) the data messages transmitted or received by any radio and (*ii*) the performance of the SAT detection and phase-range measurement circuits.

A lamp and display panel provides a manual capability to load commands into the MTFC and to observe its bit-and-flag status. This panel can manually reset the MTFC for manual error recovery and system testing.

5.4 Typical test operation

All tests are controlled by the MTSO, which also has to operate on some of the data to arrive at the desired measurement. The following sequences show the test procedures but do not necessarily correspond to specific MTSO test algorithms.

5.4.1 Transmission power and frequency tests

To measure transmitted power, the power from the forward-power coupling ports of the directional couplers is summed and routed via a switch to the mixer input of the test receiver. Power from the reflected-power coupling ports of the directional coupler is summed and connected through a second position of the switch to the mixer input. After determining that the channel fequency to be tested is not in use on any of the antennas, the MTSO uses the test synthesizer to tune the test receiver to the desired frequency and energizes the appropriate transmitter. Transmitter forward or reflected power, depending on the position of the switch, is read by means of a calibrated voltmeter and transmitted to the MTSO. The application of appropriate scale factors permits calculating the power into the antenna, and return loss. These numbers are then compared against stored limits to determine whether performance is satisfactory or faulty.

With the system configured as for the power measurement, the frequency transmitted on the channel under test may also be deter-

mined. A frequency counter is connected via a switch to measure a subharmonic of the test-receiver local oscillator (LO/4) and the IF frequency from the test receiver. The counter display may be read locally or transmitted to the MTSO. The transmitter frequency may be calculated as $4 \times (\text{LO}/4) + \text{IF}$.

Maintenance of the clock systems also requires measurements of the master oscillator distribution bus frequency (228 MHz), the low-frequency group of clocks, and the SAT frequencies. Any such frequency may be individually measured on command from the MTSO.

5.4.2 Other radio measurements

To measure phase deviation, the SAT that is continuously modulating the transmitter channel is measured. The modulated discriminator output of the test receiver is measured locally using the MTF voltmeter. The voltmeter measurements are returned to the MTSO and compared to fixed, predetermined tolerance numbers.

To test whether the receiver sensitivity is within limits, the MTSO, after ascertaining that the channel frequency to be tested is not in use, uses the synthesizer to tune the test generator to the desired receiver frequency. The output of the test generator passes through a variable attenuator and a switch to the directional coupler of either diversity input of the receiver under test. The MTFC switches the attenuator to its higher attenuation position. Noise-quieting of the receiver under test is verified at the MTSO. The output of the test generator is then switched to the other diversity input and the noise-quieting verified again. The two measurements are compared against a stored limit as a go/no-go test for each diversity section of the receiver.

To measure the audio output quality of the receiver, the MTSO applies a standard test tone to modulate the test generator over the voice trunk. The attenuator is switched to its lower attenuation state. The audio output from the receiver under test is verified for presence at the MTSO.

5.4.3 Data radio interface measurements

The test receiver and generator can receive and transmit serial high-speed data. This capability allows simple tests to be performed on the setup radio interfaces and voice radio data interfaces. To check the forward setup channel interface, a special 200-bit serial data message is transmitted via the setup transmitter and its interfaces to the test receiver. The test receiver sends the received data to the MTFC, where it is stored in temporary memory. The controller then does a bit-by-bit comparison of the message with an identical message stored in its program memory and generates an "all-seems-well" message if the two messages check. The reverse setup channel is tested in the same manner except that the roles are changed—i.e., the test generator

transmits a message to the setup receiver and its interfaces where it is received, reformatted, and sent via the controller and the data link to the MTSO for checking. The voice radio data interfaces are checked in a similar fashion.

VI. POWER SYSTEM

In the Chicago developmental trial, the primary power system for each cell site is the Western Electric type 111A. The input to this system is commercial three-phase, four-wire, 208-volt, 60-Hz power. Its output is a nominal +24 volts with a capacity of up to 800 amperes. A J87123 battery plant floats across the rectifier outputs and provides an emergency power source in case of loss of commercial power.

The electronic equipment operates mainly from dc voltages at the levels of +5, ±15, and +24 volts. Commercial 60-Hz ac power is used for cooling fans in the radio and data frames and for the commercial voltmeter and counter in the MTF. An inverter can develop the necessary 110-volt, 60-Hz power from the battery plant during commercial power failure so that system operation and test can continue.

The +24-volt battery supply is distributed to all cell-site frames. The +24-volt loads are powered directly from the nominal +24-volt* battery busses. The +5- and ±15-volt loads derive their power from dc-to-dc converters. The total 24-volt load amounts to 300 amperes for a system with only one radio frame, 430 amperes with two radio frames, and 560 amperes with three radio frames. In all cases, another 100-ampere capacity has been included in the power plant for battery charging. Where the radio frames are not fully loaded with radios, or when all radio transmitters are not operating, these loads will, of course, be less.

VII. PHYSICAL DESIGN

The AMPS cell site is functionally and physically divided into frames of radio control and transmission equipment, a power system, antenna interface equipment connecting the radios to the outside antennas, antennas, cables, and supporting mast and structure. The cell site equipment must be capable of being located in a variety of places. The Chicago developmental system† includes (*i*) small self-contained buildings with a dedicated antenna mast, (*ii*) small self-contained buildings adjacent to an existing microwave tower to make maximum use of tower facilities, and (*iii*) a portion of the top floor of a large downtown central office building.

Rented building space of many types may be necessary for future growth. In addition, designs must consider the visual appearance of

* Which can vary between 21 and 28 volts, depending on the battery's state of charge.

† The developmental system layout is described in Ref. 11.

buildings; the antenna mast assembly, because of its height, will be especially visible and may draw the attention of local zoning boards.

Since the AMPS is a new service using largely new equipment, there was little to guide design decisions. Thus, there is a need to learn how the equipment will function and how people will use the service. Production will be low in volume for the early years, relative to other telephone equipment. For these reasons, the physical design concept chosen for the Chicago trial equipment sought to fill several objectives. The design had to be flexible to accommodate many anticipated early changes and to make maximum use of existing general-purpose hardware to avoid the expense, time, and tooling necessary to generate a customized equipment technology. The equipment was partitioned into smaller units than will be ultimately optimum so that the system would be more flexible and responsive to changes. This section contains a general physical description of the equipment designed to accommodate these considerations.

The cell-site equipment may be housed either in a dedicated building or in an appropriately located existing building. The approximate floor area required for the trial equipment is 22 by 23 ft with a vacant wall or ceiling required for the placement of antenna interface equipment such as the filter divider panels. The cell sites should take advantage of existing facilities where possible to meet operational and economic objectives.

The outside equipment consists initially of omnidirectional, vertically polarized transmit and receive antennas mounted on a freestanding mast, or other tower. These antennas must be located and installed with particular attention to height and diversity spacing requirements. As the system grows into a directional configuration, the antenna array will also require directional transmit and receive antennas. The antennas are connected to their respective filter panels within the building via coaxial cable feedlines that pass into the building through a cable hatch plate. An effective grounding system is required to minimize voltage potentials generated by lightning. The building and mast must be surrounded by an external ring ground, and the interior of the building must contain another ring ground with all equipment frames and metal cabinets connected to it.

A typical interior equipment layout is shown in Fig. 2. The antenna interface equipment is supported by a wall and located as near as possible to the hatch plate. The radio control and transmission equipment is housed in standard Bell System Electronic Switching System (ESS) frames, 7 ft high, 2 ft, 2 in. or 3 ft, 3 in. wide, and 18 in. deep. The end guards selected are 24 in. deep to protect the equipment wiring. The ESS cable trays on top of the equipment bays are used for frame interconnection paths, and most of the interbay cables are equipped with connectors. The frames are sufficiently modular in design so that

different channel capacity requirements of the various cell sites can be easily accommodated.

The remaining equipment, which may be considered as support equipment, consists of the power plant, battery stand and batteries, inverter, fuse panel, and air pressurization equipment.

7.1 Technologies

7.1.1 Components

Circuits for the AMPS cell-site equipment use both conventional discrete components (transistors, diodes, capacitors) and silicon integrated circuits (ICs). Analog and digital ICs with 5-volt and 15-volt power are used. Western Electric, commercial, and KS specification dual-in-line packages are employed, with most ICs having 16 pins. For ongoing designs beyond the trial hardware, additional emphasis is expected to be placed on using the highest-reliability devices available at acceptable costs. Many of the radio devices for use in the 900-MHz radio band are technologically new, and the technology is rapidly changing due in part to the considerable interest in this band generated by several new radio services, including AMPS.

7.1.2 Circuit boards

In addition to the conventional printed wiring board design, boards with wire-wrap interconnected socket pins on 1/10-in. centers are used in many of the plug-in logic circuit packages to give maximum flexibility for changes introduced during the trial. These will be replaced by double-sided or multilayer epoxy-glass printed boards on subsequent production of additional systems. Where circuits are replicated many times or high confidence existed that no changes would be made, conventional double-sided printed-wiring boards were chosen to save space and reduce cost.

7.1.3 Backplane wiring

The next level of interconnection is between circuit packs to merge them into panels or groups of panels. The logic boards are connected through the WE 947 backplane connector with an array of wire-wrap pins of 1/8-in. centers. Most of the power wiring is printed on the backplane. Where possible, a ground plane is also printed on the backplane to minimize noise. Most of the panel-level signal wiring for these panels is 30-gauge and is wrapped with an automatic wiring machine. Connections that require twisted pair or twisted-shielded pair for noise or impedance-matching considerations are manually installed after machine wrapping is completed. Figure 21 is a photograph of some of the backplane wiring.

The boards in the analog circuit sections of the frames generally use a lower-density connector, and the wiring between connectors is man-

Fig. 21—Backplane wiring showing both local wiring and interpanel cabling.

ually wrapped. RF signals within a frame are routed using 0.141-in. semirigid coaxial cable terminated in SMA or type-N connectors. The semirigid cable minimizes spurious radiation and pickup and provides low signal loss in constrained space.

7.1.4 Frame wiring

The next level of wiring is between panels, or between the top of the frame and panels. For logic and audio signals, this wiring is generally twisted pair or twisted-shielded pair, depending on the sensitivity of the signal and the length of the run. Power wiring from the power modules uses large-gauge wire or laminated bus bars where the amount of current is large and space is limited. Semirigid coaxial cables are used for radio frequency signals.

7.1.5 Interframe cabling

Most wiring between equipment frames is via connectorized cable between interconnection panels at the top of the frames. Standard twisted pair cable is normally used, with twisted-shielded pair being used where extra shielding is required. The RF signals between frames, and between filter panels and frames, are routed on RG-214 coaxial cables fitted with type-N connectors. The filter panels are connected to the antennas with 1-⅝-in. semirigid coaxial cable between the transmitter filter panel and the transmit antennas and ⅞-in. semirigid coaxial cable between the receiver filter panel and the receive antennas.

7.2 Equipment and apparatus mechanical design

7.2.1 Circuit package mechanical design

The individual circuit packages for the cell-site equipment are all apparatus-coded and are of three general types. The most used are F-coded (a temporary manufacturing code for use during a trial period) packages that use either printed or wire-wrap boards for component interconnection and are fitted to the 946A circuit pack connector (see Fig. 22). These cards are mounted into 80A apparatus housings and connected to 947C backplane connectors. The F-coded circuit packages are used primarily for logic and control circuitry in the data frame and in the controllers of the line supervision and maintenance and test frames. They also contain some analog circuitry associated with the controllers. The main audio and signaling data circuits that are required on an individual channel basis are implemented on seven PC codes. These codes are also mounted in 80A apparatus housings but use gold fingers on 0.060-inch-thick, printed double-sided, epoxy-glass boards fitted directly into a backplane connector to reduce cost relative to the F-code boards (see Fig. 23). The third type of board used primarily for analog circuits is an A-code board also on epoxy glass but

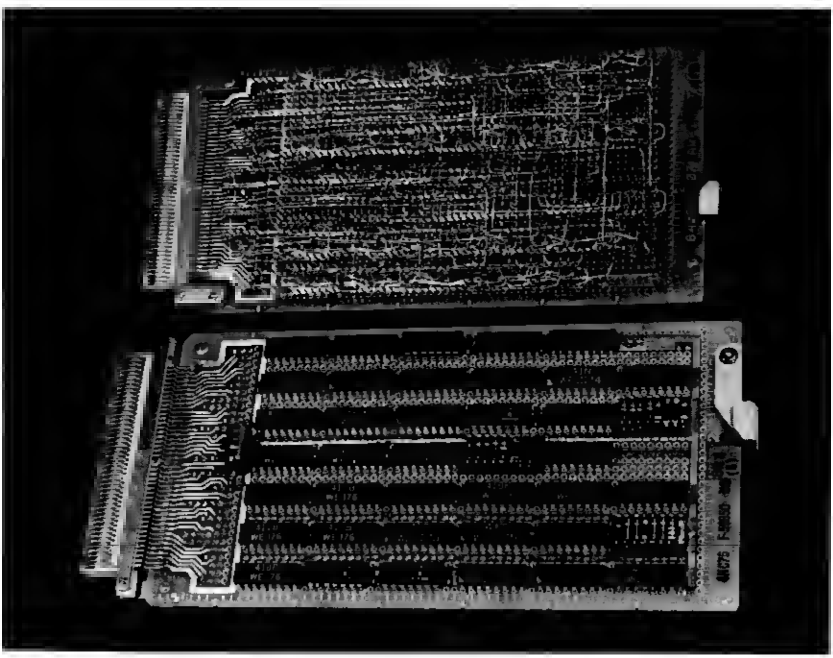


Fig. 22—F code circuit package.

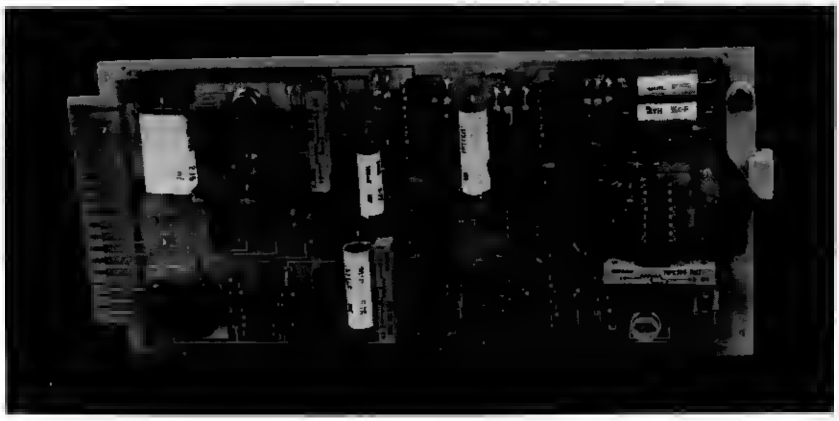


Fig. 23—PC code circuit package.

0.090-inch thick, with gold fingers that fit into a 36B apparatus housing containing 905B type connectors (see Fig. 24).

7.2.2 Mechanical design of the radio modules

Radio modules in the data frame perform setup, locating, and signaling functions. Other radio modules in the radio frame perform voice channel functions, a capability which can be increased on a module-per-voice-channel basis. Test radio modules are also housed in the maintenance and test frame, along with the reference frequency equipment. The transmitters, receivers, and synthesizers were designed by Bell Laboratories and manufactured under KS specifications. To maximize early design flexibility and to minimize early tooling costs, a flexible packaging technique using three special extrusions was developed. The radio subassemblies could be developed individually and later packaged together with a minimum of circuit interaction. Figure 13 shows the voice/data transmitter with its covers removed to illustrate the packaging technique. This same general design approach was used for the voice/data transmitters and receivers, the frequency synthesizers, the test radio modules, and the reference frequency leveler amplifiers.

The other major radio module is the power amplifier unit. It is used on an individual radio channel basis and was manufactured to a KS specification (Fig. 14). The heat sink for the power amplifier was specified to be compatible with a forced-air cooling system that is part of the radio frames. Power dissipation requirements and long-life considerations indicated forced-air cooling as the best way to get a cost-effective design for the 900-MHz output-power device.

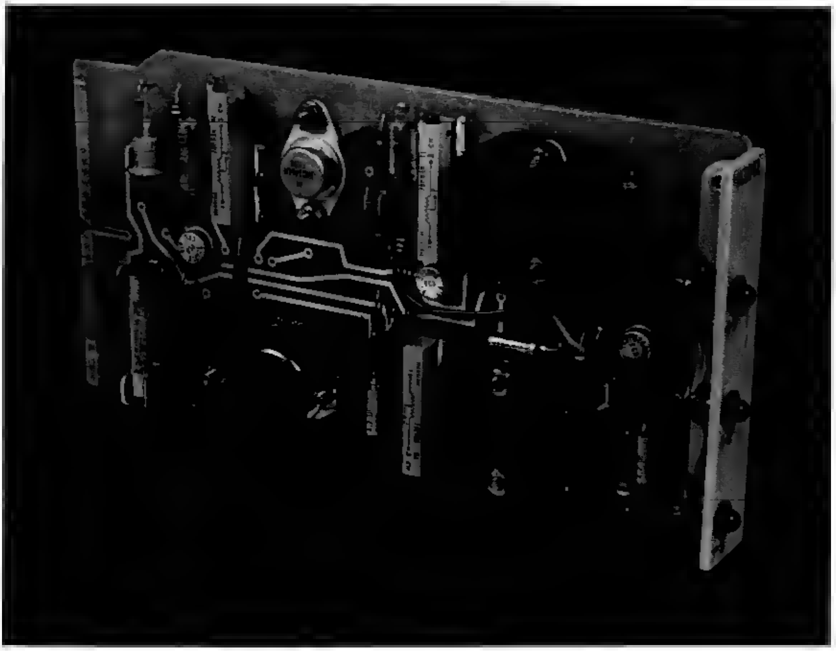


Fig. 24—A code circuit package.

7.2.3 Channel multiplexer

The channel multiplexer (see Fig. 18) is a 16-to-1 RF multiplexer, which uses individually tuned high Q cavities to combine efficiently the RF power from 16 transmitters into a single transmit antenna. The individual cavities must remain physically stable over a wide range of ambient temperature and varying power dissipation. To accomplish this, the cavities are made of invar, a steel formulation with a very small coefficient of thermal expansion. The cavities are plated with at least one-half mil of copper to provide good electrical conduction in the skin region at RF. A final thin layer of gold plate on the copper maintains good conduction at the material joints and ensures a good interface to the cavity interior. A fan cools the combiner, aids its temperature stability, and stabilizes the characteristics of the combiner stripline.

7.2.4 Power units

The primary power for the cell-site equipment is a +24-volt dc reserve power system, described in more detail in Section VI. The 24-volt direct current is distributed to each frame and either is used directly, in the case of RF power amplifiers, or is converted to the correct, regulated power needed by each frame. This conversion re-

quires the use of various quantities and combinations of four plug-in codes of dc-to-dc converters. One unit, coded 121A, is of the nominal 50-watt type which occupies only one-half of an apparatus housing, and has an output capacity of 2.3 amperes at −14.7 volts. The other three units—coded 122D, E, and F—are of the nominal 150-watt type, occupy a full apparatus housing, and have outputs of 7 amperes at +14.7 volts, 7 amperes at −14.7 volts, and 17.5 amperes at +5.3 volts, respectively. Although each of these codes was specified to unique AMPS requirements, they are part of a larger standard family of Bell System power converters. The converters of each code within a frame are connected to a common bus. Moreover, at least one extra power unit is provided for redundancy on each bus. In general, the loss of any single power unit will result in an alarm but no loss of service to customers.

7.2.5 Antennas and mast

Transmit and receive antennas for the trial system are high-gain, omnidirectional, and vertically polarized. They are end-supported but are electrically center-fed to minimize antenna-pattern squint-angle change over the frequency band. Two receive antennas per cell site provide diversity and there is one transmit antenna per radio frame (16 radio channels). The antennas are approximately 13 feet long, including the mounting, and are placed in a 2-½-in. diameter fiberglass housing. When the system requires directional capability, the omnidirectional antennas will be augmented by directional transmit and receive antennas.

The omnidirectional antennas are typically mounted at the corners of a triangular platform (about 10 feet on a side) at the top of a 150-foot free-standing steel mast, as shown in Fig. 25. Later, the directional antennas will be mounted behind the contoured dielectric covers. There will be two receive antennas (for diversity) and one or two transmit antennas per face. Where an existing structure such as a microwave tower or downtown central office building is used, special mounting arrangements must be engineered for each site. As the system grows and cells are subdivided, the antenna height may be reduced to about 100 feet.

Since the vertical pattern has a half-power beamwidth of about 7 degrees, the omnidirectional antenna has the disadvantage of being susceptible to relatively small angular deflections from vertical. The antenna mast and platform were designed to minimize deflection and cost. The two major sources of deflections are the wind and uneven solar heating of the steel mast. In general, the antenna hardware was designed to meet two wind criteria; (*i*) system operation within specifications for normally encountered wind conditions, and (*ii*) survival under extreme but rare conditions such as winds up to 100 mph.[12]

The RF transmission line to the antennas uses semirigid air-filled

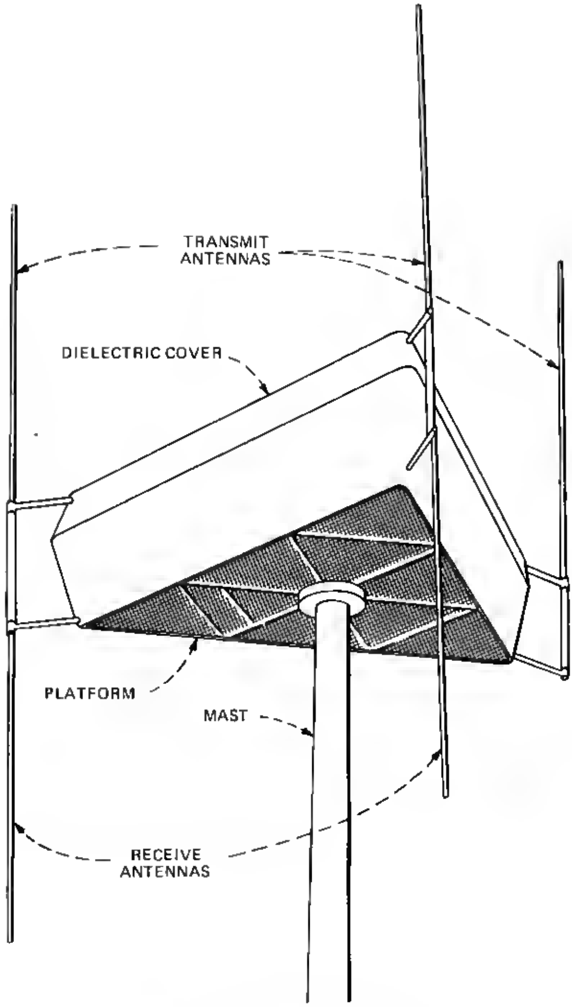


Fig. 25—Mast-mounted antennas.

coaxial cables to keep the RF losses low. The cables are routed inside the mast through a suspended conduit cluster. The conduit allows for cable system growth and ease of replacement if required. The interior mounting provides protection to the cables and significantly improves the visual appearance. An air pressurization system keeps the cables pressurized and dry internally.

APPENDIX

Operating Theory of the Two Branch, Equal Gain, Diversity Combiner

In Figs. 19 and 26, consider the two 1.8-MHz input signals, A and B, which arrive from the two 1.8-mHz IF amplifiers.

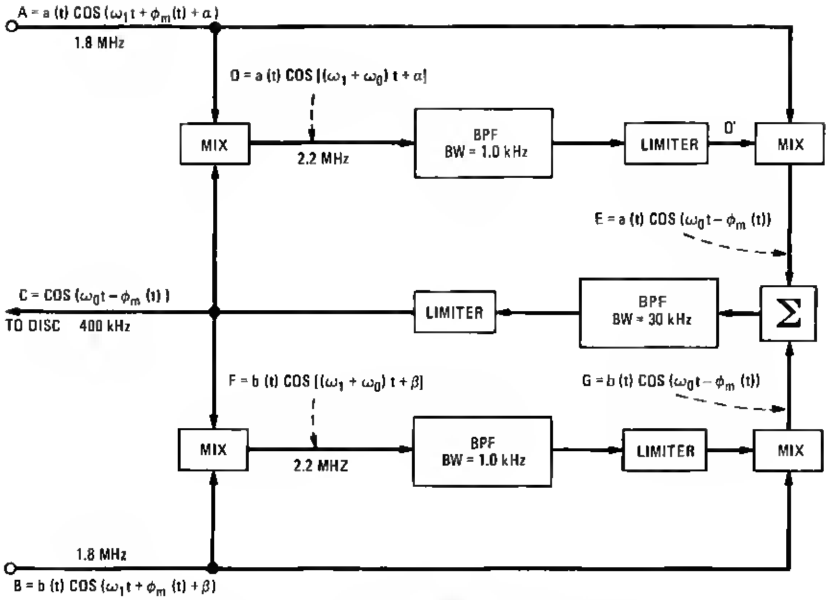


Fig. 26—Two-branch equal-gain diversity combiner.

$$A = a\ (t) \cos\ (\omega_1\ t + \phi_m\ (t) + \alpha),$$
$$B = b\ (t) \cos\ (\omega_1\ t + \phi_m\ (t) + \beta),$$

where

$a\ (t)$, $b\ (t)$ are slowly varying uncorrelated Rayleigh amplitude functions,

$\omega_1 = 2\pi$ (1.8 MHz) = carrier frequency,

$\phi_m\ (t)$ = the voice phase modulation, and

α, β = slowly varying, random, uncorrelated, carrier phases of channels A and B, respectively.

It is the function of the combiner to co-phase A and B (set $\alpha = \beta$), so that A and B can then be coherently added together. Assume that this regenerative loop is already in operation so that there exists the constant amplitude output signal

$$C = \cos\ (\omega_0\ t - \phi_m\ (t)),$$

where

$$\omega_0 = 2\pi \text{ (400 kHz)} = \text{output signal.}$$

Note that α and β are absent.

The upper left mixer (modulator) takes the product A and C whose upper sideband is

$$D = a\ (t) \cos\ [(\omega_1 + \omega_0)\ t + \alpha].$$

Note that the voice modulation term $\phi_m(t)$ has been removed, but the random modulation α remains.

The signal D, which is a 2.2-MHz carrier with slowly varying phase modulation, passes through the narrowband filter and limiter, which removes the amplitude term $a(t)$. The subtleties associated with the choice of the filter bandwidth are thoroughly discussed by Halpern[9]. The resulting constant-amplitude signal,

$$D' = \cos [(\omega_1 + \omega_0) t + \alpha],$$

is product-modulated with A in the upper right-hand "mixer." The lower sideband is given by

$$E = a(t) \cos [\omega_0 t - \phi_m(t)].$$

Note that this second modulation process has removed the random phase term α.

By similar reasoning, the signal

$$G = b(t) \cos [\omega_0 t - \phi_m(t)]$$

is generated by the lower regenerative loop. E and G, being phase-coherent, can be summed in a hybrid. This sum passes through a third limiter where the amplitude function is removed, giving the constant amplitude output signal

$$C = \cos [\omega_0 t - \phi_m(t)].$$

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